ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Enis AYTAR

DEVELOPMENT AND IMPLEMENTATION OF A NEW INTELLIGENT SAFETY PACKAGE SOFTWARE FOR COMMERCIAL VEHICLES

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 27/07/2015.

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ABSTRACT

MSc THESIS

DEVELOPMENT AND IMPLEMENTATION OF A NEW INTELLIGENT SAFETY PACKAGE SOFTWARE FOR COMMERCIAL VEHICLES

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The aim of this thesis is to design and develop a software for Intelligent Safety Package, working parallel to main brake system and consisting of the Hill Start Assist Function (Hill - Holder), Automatic Park Brake and Halt Brake functions. The designed system is capable to collect the data from the vehicle CAN (Controller Area Network), MUX (Multiplexer) and sensors. ZR-32 (Body Controller) activates or deactivates appropriate brake force when needed by the intelligent safety package software. The necessary software for the intelligent safety package algorithm is designed by LogiCAD software. Information and warning messages related with vehicle system and intelligent safety package are displayed on an LCD screen which is placed on the instrument panel. The necessary software for the instrument panel is designed by Cavtan software.

Keywords: Hill Start Assist Function, Automatic Park Brake, Halt Brake, CAN, ZR-32

ÖZ

YÜKSEK LİSANS TEZİ

TİCARİ ARAÇLARA ÖZGÜ YENİ BİR AKILLI GÜVENLİK PAKETİ İÇİN YAZILIM GELİŞTİRİLMESİ VE UYGULAMASI

Enis AYTAR

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Bu tez ile ana fren sistemi ile paralel olarak çalışabilen; yokuşta kalkış destek sistemi, otomatik park freni ve durak freni fonksiyonlarını içeren bir akıllı güvenlik paketi yazılımının geliştirilmesi amaçlanmıştır. Geliştirilen sistem verileri araç üzerindeki CAN hattından, multiplex sistemin girişlerinden (MUX) ve sensörlerden okumaktır. Merkezi işlemci (ZR-32) gerektiği zamanlarda uygun fren kuvvetini akıllı güvenlik paketi yazılımı ile aktif veya pasif edecektir. Akıllı güvenlik paketi algoritması için gerekli yazılım LogiCAD yazılımı ile tasarlanmıştır. Araç sistemi ve akıllı güvenlik paketi ile ilgili bilgi ve uyarı mesajları gösterge paneli üzerindeki LCD ekran ile görüntülenmiştir. Gösterge paneli için gerekli yazılım Cavtan yazılımı ile tasarlanmıştır.

Anahtar Kelimeler: Yokuşta Kalkış Destek Sistemi, Otomatik Park Freni, Durak Freni, *CAN*, ZR-32,

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I am heartily thankful to my supervisor, Asst. Prof. Dr. M.Uğraş CUMA, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject.

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1. INTRODUCTION

In recent years, traffic problems caused due to increasing number of vehicles and insufficient transportation infrastructure lead to requirement of much more complex and advanced safety based algorithms. Passengers are disturbed because of following reasons:

- Short stopping distance
- Sudden braking
- The risk of vehicle movement before all passengers get in or out from the vehicle safely
- Vehicle rolling backwards during a hill start

Therefore, the necessity of developing advanced safety algorithms which eliminate these disadvantages of the currently available safety packages has been widely attracted interests of the researchers and industrial partners.

Main braking systems of the conventional vehicles can not be controlled automatically from the outside since they work completely based on the principles of pneumatic. With respect to the safety package software developed in this thesis, it is aimed at controlling the main braking system by designing a parallel automatic braking algorithm covering the functions described below:

1. Hill Start Assist Function (Hill - Holder): During an initial start on a hill, this function allows the developed software to provide a safe and comfortable start without rolling backwards by activating the service brakes under right conditions and timing.
2. Automatic Park Brake Function: This function is activated in case of leaving the vehicle without manually activating the park brake system. In this situation, the park brake will engage automatically to block the movement of the vehicle.

3. Halt Brake Function: This function activates the safety package while passengers are getting in or out from the vehicle at bus stations, so that guarantees to block of the vehicle movement until doors are closed and passengers are transferred safely.

The Intelligent Safety Package developed with the intended design of the software yields innovative features described as:

- This study is a new beginning for the software based vehicle safety systems which are not produced in our country currently.
- Tilt sensor is used for the first time in such an application that was developed for commercial vehicles on the market.
- This study carries a new feature that has never been used before as the information obtained from pressure sensors placed in the vehicle is processed via the software; so that the vehicle load is instantly calculated and feeded the braking system.
- Information and warnings about the status of the safety package functions are displayed on the LCD screen for the driver.
- The algorithm creates the characteristic of the ideal braking by calculating how much pressure force should be applied to the brakes under which conditions.
- Automatic park brake function is activated if the driver leaves the vehicle without activating the park brake and later this property will be used in different emergency situations by improving this function.
- Halt brake function is developed to guarantee to block vehicle movement, this system is activated while passengers are getting in or out from vehicles at bus stations and is deactivated after doors are closed and passengers are transferred safely.
- Drivers can deactivate the automatic park brake function manually via a sealed switch when there is a situation that the vehicle should move or there is a problem with the system.

- Parameters of the safety package functions can be adjusted according to customer preferences and using conditions. Companies developing these products don't provide such properties on the market currently.

Hill start applications proposed in the current literature suffer due to insufficient level of efficiency and quality to achieve the desired tasks. The deficiences of the examined studies were analyzed and the ideas of the thesis were matured with these references.

Material and Method: The following materials are used for intelligent safety package software application.

LogiCAD Software and Dongle: These software tools are used to create the logic function for safety package software algorithm.

CAVTAN Software and Dongle: These software tools are used to display necessary information and warnings to the driver about the current application results of the safety package software algorithm.

CANalyzer: The program is used to observe the CAN (Controller Area Network) and analyze the safety package software application results.

MATLAB – SIMULINK: The program is used to model the vehicle and simulate the results of the safety package software algorithm.

Collecting data from CAN bus and sensors: A tilt sensor, which is a sensitive and fast measurement tool, is used to calculate tilt data which is one of necessary parameters for safety package software algorithm to determine whether the vehicle is on the hill or not. The data from pressure sensors that are placed to the vehicle blowers are calculated and the weight of the gravity center is determined for one of another necessary parameters for safety package software algorithm. Data from these sensors are gathered on Multiplexer (MUX) module and transferred to the vehicle control unit ZR-32. The same method is applied to obtain the data such as park brake switch, vehicle speed, passenger door switch that are needed for the safety package software algorithm.

Developing LogiCAD software that activates or deactivates appropriate brake force when needed: Developed system is controlled by LogiCAD based PLC

software. External Brake Request feature of the main brake system is used to activate or deactivate the appropriate amount of the brake force when needed. Proportional brake force is adjusted with External Brake Request feature via CAN messages EBC1, EBC5 and XBR. Hill Start Assist Function can be activated when the vehicle is in reverse gear with the developed system and remains active until necessary conditions exist to deactivate Hill Start Assist Function. Developed system works parallel to existing brake system. In this way, stability of the existing system is protected.

Developing Halt Brake algorithm by LogiCAD software: Halt brake algorithm, which is one of the safety package functions, is aimed at working more safely and functionally than existing applications with developed safety package software. Halt brake system is activated according to signals such as halt brake switch, door open, vehicle speed, handicapped lift open, park brake switch and throttle pedal. Halt brake system is also activated when articulation system ECU releases interlock message to stop the vehicle completely.

Developing Automatic Park Brake algorithm by LogiCAD software: Automatic park brake becomes active after checking the vehicle speed when the driver turns off the ignition in new designed software. In this study, the driver can cancel automatic park brake with a sealed switch when the driver needs to move the vehicle by pushing. New designed automatic park brake isn't cancelled without pushing throttle pedal when the vehicle starts running to prevent vehicle movement if the vehicle is parked on a hill.

Developing Cavtan software that display necessary information and warnings to driver: Information and warning messages related with vehicle system are displayed on an LCD screen which is placed on the instrument panel. The necessary software for the instrument panel is designed by Cavtan software.

Every fault (diagnosis) regarding with the vehicle or the safety package can be monitored via K-LINE. If any fault is detected and blocks working properly of any function of the safety package, the corresponding function(s) will be cancelled temporarily and related warnings which are activated by Cavtan software will be displayed to inform the driver. Overall system diagram is shown in Figure 1.1.

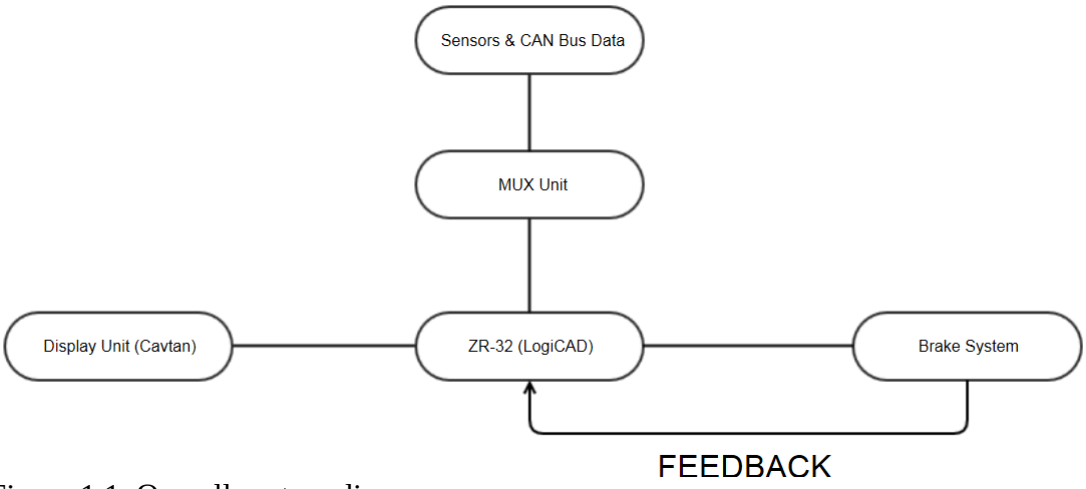


Figure 1.1. Overall system diagram.

During the initial preperation of the thesis content, it was planned to use a vehicle with ABS/ASR braking system. But, when market demands are checked one more time before starting the thesis, it is realized that most of customers prefer EBS braking system instead of the ABS/ASR. Thus, it is decided to use EBS braking system and change our algorithm according to it. Initially, it is planned to use a proportional valve for the hill start assist function, but we are not allowed to add a new valve to EBS braking system due to main brake company restrictions. Therefore, it is decided to activate hill start assist function with external brake request feature of EBS braking system. CAN messages EBC1, EBC5 and XBR are used instead of using a proportional valve for the hill start assist function.

The thesis consists of six chapters. First chapter is the introduction. In this chapter, aim of the thesis, material and method which will be used during the thesis are presented. Second chapter reviews commercial vehicle safety system. In this chapter, literature review, anti-lock braking system (ABS), anti-slip regulation (ASR) and electronically controlled brake system (EBS) are reviewed. Third chapter is dedicated to commercial vehicle control system. In this chapter, vehicle electronic control system and CAN communication protocol are explained. Fourth chapter introduces the intelligent safety package software. In this chapter, automatic park brake, halt brake and hill holder approach are presented. Fifth chapter is for the simulation and implementation. In this chapter, driveline tools of the Matlab

Simulink, simulation on the Matlab Simulink, simulation and implementation results are presented. Finally, sixth chapter is conclusion. In this chapter, conclusion of the thesis is briefly explained.

2. COMMERCIAL VEHICLE SAFETY SYSTEMS

In this chapter, literature review, anti-lock braking system (ABS), anti-slip regulation (ASR) and electronically controlled brake system (EBS) are presented.

2.1. Literature Review

There is a great amount of studies in the literature about the hill start assist function and automatic park brake which are a part of the intended design of the software. While a number of the studies are scientific publications, the majority of studies are patents and commercial studies.

Fontaine's patent presents an automatic park brake system, in other words emergency brake system, which is activated when the driver stops the engine or the vehicle stops reluctantly. This system is cancelled when the driver restarts the engine and pushes the throttle pedal. An automatic parking or emergency brake system for motor vehicles comprising means by which the parking or emergency brakes of a motor vehicle will be applied automatically when the engine of the vehicle is shut off or stalls, and by which the brakes will be released automatically and immediately when the engine is started, and then only when the driver's seat is occupied and pressure exerted on the accelerator pedal. The described means includes also an arrangement by which, when the vehicle is halted at crossings and elsewhere on either level or hilly roadway, the parking or emergency brakes will be automatically applied within about three seconds after the vehicle reaches to a complete stop and thus creeping of the vehicle is prevented, and this is particularly desirable when it is one of the automatic transmission type.

A cylinder-and-piston is operated by fluid pressure from a steering pump on the vehicle to release these brakes when the engine is started. Once they are released, a valve is closed automatically to hold the fluid pressure in the cylinder and thereby maintain these brakes released, and another valve is opened to connect the steering pump to power steering apparatus on the vehicle. A portable pressure pump may be

used to pressurize the cylinder for releasing these brakes, when desired (Fontaine, 1974).

Fulmer, Peebles and Steininger's research on the hill holder system involves hydraulic booster connected to control software to support the vehicle during the hill start. The control sofware provides brake force by actuating the three-way solenoid valve which supplies fluid pressure to booster chambers when the vehicle application software determines that vehicle is on the hill, engine is running, clutch is active and the speed of the vehicle is zero. A brake booster connected to a control circuit provides a system for the continued braking of a vehicle when the vehicle is situated on an incline and the brake pedal is released by the operator. Continued brake application is accomplished by utilizing a control circuit responsive to vehicular attitude, clutch pedal position, ignition status, vehicular speed and vehicular direction. The control circuit is connected to the combination of a check valve and three-way solenoid valve connected to a movable wall brake booster. The combination valve is connected to a flexible hose disposed interiorily of the booster, the other end of the flexible hose connected to the input opening of a three-way poppet valve located at the central hub of the booster. When the control circuit senses that the vehicle is on an incline, the clutch pedal depressed, the ignition on, the speed is zero and the vehicle not backing up, it actuates the three-way solenoid of valve which continues to supply a first fluid pressure to the front booster chamber while supplying a second fluid pressure for the rear booster chamber via the flexible hose and poppet valve. The vehicle operator may release the brake pedal which returns slightly toward an inactive position and which opens slightly valve, with the brakes remaining activated because the second fluid pressure is provided to the rear chamber via the hose connection and valve to maintain the axially displaced position of the movable wall (Fulmer, Peebles, Steininger, 1987).

Hayes-Sheen's study focuses on a system which locks brakes by actuating auxiliary brake system when the driver turns off ignition for a vehicle that has hydraulic brake system. This system consists of a safety switch which works in conjunction with ignition switch. This safety switch must be opened together with ignition switch to cancel automatic park brake to allow the vehicle movement. An

automatic brake locking system, for locking the brakes of a vehicle having a hydraulic brake system, is operated every time when the ignition switch is turned off to apply pressure through an auxiliary brake actuating device to lock the brakes and hold them locked until the auxiliary brake actuating device is released. A safety switch is provided to operate in conjuction with the ignition switch, so that both the safety switch and the ignition switch must be operated to an 'on' position to release the auxiliary brake actuating device allowing normal operation of the vehicle. Turning on the ignition switch without operation of the safety switch does not permit movement of the vehicle since the auxiliary brake actuating device continues to be operated (Hayes-Sheen, 1990).

Braun's patent presents a hill holder system for a truck with hydraulic brake that supports driver during uphill or downhill movement. This system becomes active if the vehicle application software determines that the vehicle speed is lower than reference speed during uphill movement by activating the brake control valve with right conditions and timing (Braun, 1992).

Smale's patent presents an ignition-controlled parking brake interlock for a vehicle. The parking brake operating lever is latched in brake-applied positions by engagement of a lever-mounted pawl with fixed sector. A solenoid is movable between positions blocking and unblocking movement of the vehicle ignition to off. A lock bar carried by the lever is movable by a second solenoid between positions blocking and unblocking movement of the pawl to release the lever. In one embodiment, a brake lever position switch and a switch operated by the second solenoid control solenoid operation to prevent ignition key removal unless the parking brake is applied and to prevent parking brake release unless the key is inserted and the ignition moved to run. In another embodiment, bi-stable solenoids are controlled by a controller that is provided with high and low current inputs from branch circuits that include control switches operated by ignition position and parking brake lever position (Smale, 1997).

Maslonka, MacGregor and Hamilton propose a safety-enhancing automatic air parking brake actuator system that automatically actuates the air brakes in an engaged condition when one or more dangerous conditions exist at various stations

around/in the vehicle or equipment. The preferred actuator system operates on the principle that the brake actuator system is electrically connected to the various stations and when a circuit including the actuator unit is interrupted, a solenoid valve of the actuator system closes and vents, to cut off the air supply to the air brakes to engage the brakes. The stations may include the vehicle ignition, one or more doors, a wheelchair lift, a dump truck bed, a backhoe arm, or other equipment. By turning off the vehicle ignition switch, which ignition system is preferably the power source for the actuator unit, or by interrupting any of the various circuits to the various stations, the actuator unit will trip, that is, the solenoid valve will close and vent air, thus, applying the brakes. The actuator system may be installed in an air brake system by placing the brake actuator unit in-line between the air source and the air brakes. The solenoid valve of the brake actuator unit has an exhaust vent which releases air-line pressure when the solenoid valve is de-energized by any one of the various brake actuator circuits being interrupted. The brake actuator unit may be installed adjacent to a conventional loading valve, or may be installed in the place of a conventional loading valve. In use, if the driver does not manually set the parking brake whenever there is an action about to take place that requires extra caution and care, the invented system sets the air brake for him/her (Maslonka, MacGregor, Hamilton, 2001).

Holl's study on hill holder system controls brakes by monitoring wheel speed. When the system is active during a hill start, the coming pressure of one of the locked wheels is decreased simultaneously when the driver releases brake pedal. If the speed of this wheel is greater than the reference speed than the hill holder system is cancelled during hill start (Holl, 2002).

The invention of the patent registration to Ertuğrul Cihan includes a system for vehicles with pneumatic brake system. During a hill start, this system controls the parking brake valve and air signal in the relay valve line mechanically to prevent rolling backwards without using service brake (Cihan, 2008).

Fujita's patent presents an electric parking brake system which includes an electric parking brake mechanism that consists of a brake which suppresses rotation of a wheel and an electric motor which applies or releases the brake and that

maintains a vehicle at a standstill while the brake is applied. A parking switch selectively outputs an application command for applying the brake and a release command for releasing the brake in response to an operation of an operating portion for the parking switch. A parking switch malfunction determination unit determines whether the parking switch malfunctions and a parking brake automatic control unit automatically applies the brake by operating the electric motor when an ignition switch of the vehicle is turned off in response to an operation of an operating portion for the ignition switch, in a case where the parking switch malfunction determination unit determines that the parking switch malfunctions (Fujita, Yamashita, Kondo, Yamamoto, 2008).

Ingemar and Anders's study presents an automatic park brake which is activated whether the driver cabin is locked or not for commercial vehicles such as trucks. In this system, automatic park brake is activated if the driver forgets activating park brake but locked the door of the vehicle. In this way, stealing the vehicle by pushing backwards or rolling backwards of the vehicle on a hill is prevented (Dagh, Trygg, 2009).

Setlak and Krzyszkowski integrate their hill holder design to ABS brake system which is located in Fiat Panda brand car and they present an alternative which has a lower cost than Fiat Panda's safety system that includes ABS and additionaly ASR. They design and build the model of the electric parking brake in automobiles. The microprocessor control system of the hill holder brake shall be equipped with self-locking feature when it detects a vehicle stop and tilt (front of the car is higher than the rear). The system should automatically let go of the brake when starting the vehicle, and should provide an opportunity for traditional, hand-brake control of the rear axle. The system is designed to enable the driver on a hill to start without a risk of rolling back. Data such as wheel speed, throttle pedal position, tilt position, brake, clutch and ignition switch is processed on a system which is controlled by the software developed on ATmega8 (Setlak, Krzyszkowski, 2010).

Bradley's study of hill holder system involves pressure reduction valve, foot brake valve and a solenoid valve which interacts with the other brake system components. When the activation of the hill holder system is needed, this solenoid

valve is actuated to fulfill related functions by signals which are sent via central control unit of the vehicle. A hill start assist system for a tractor includes a pressure reduction valve receiving air from an air supply source, a solenoid valve having a supply port connected to a delivery port of the pressure reduction valve, a double check valve receiving air from a foot brake valve and from the solenoid valve, a tractor protection valve receiving air from the solenoid valve and from front and rear brake circuits of the tractor and an inversion valve having a control line connected to the solenoid, a supply port connected to the delivery line of the tractor protection valve, an exhaust port connected to the foot brake valve and a delivery line connected to a stop light switch (Bradley, 2010).

2.2. Anti-Lock Braking System (ABS)

In this section, anti-lock braking system (ABS), theoretical ABS basics and operation of ABS are explained.

2.2.1. ABS

Anti-lock brake systems (ABS) - generally also referred to as anti-lock systems (ALS) - are designed to prevent the vehicle wheels from locking as a result of the service brake being applied with excessive force, especially on slippery road surfaces (Wabco, 2011).

The idea is to maintain cornering forces on braked wheels to ensure that the vehicle or vehicle combination retains its driving stability and manoeuvrability as far as physically possible. The available power transmission or grip between tyres and carriageway should also be utilised as far as possible to minimize the braking distance and maximize the vehicle deceleration (Wabco, 2011).

Although today commercial vehicle brakes are designed to a very high technical standard, braking on slippery roads often results in potentially dangerous situations. During full or even partial braking on a slippery road it may no longer be possible to fully transfer the braking force onto the road due to the low coefficient of

friction (friction coefficient (k)) between the tyres and the carriageway. The braking force is excessive and the wheels lock up. Locked wheels no longer provide any grip on the road and are almost incapable of transferring any cornering forces (steering and tracking forces). This often has dangerous consequences:

- The vehicle becomes unsteerable.
- The vehicle breaks away in spite of countersteering, and starts to swerve.
- The braking distance is significantly increased.
- Tractor-trailer combinations or semitrailer trains may break away or jackknife (Wabco, 2011).

On dry roads today's load sensing valves alone are often capable of preventing the wheels from locking if the vehicle is unladen; they also help the driver to effectively grade the braking process on wet road surfaces, but they are unable to prevent locking as such (no slip monitoring). In addition, they are unable to counteract any overreactions on the part of the driver, or any variances in frictional or adhesion coefficients which may apply to different sides of the vehicle, or indeed to its different axles (μ-split road surfaces) (Wabco, 2011).

Only the Anti-Lock Brake System (ABS)

- guarantees stable braking characteristics on all road surfaces.
- maintains steerability and generally reduces the braking distance.
- prevents vehicle combinations from jackknifing.
- reduces tyre wear (Wabco, 2011).

Although the ABS is an effective safety device, it can not suspend the limits defined by driving physics. Even a vehicle fitted with ABS will become uncontrollable if it is driven too fast around a corner.

So the ABS is not a licence for a maladjusted style of driving or failure to observe the correct safety distance (Wabco, 2011).

2.2.2. Theoretical ABS Basics

The brake force coefficient (adhesion) between the wheel and the carriageway determines the braking forces that can be transferred. It depends on the brake slip between the tyre and the road, and among the factors affecting it are:

- the condition of the road and the tyres
- the wheel or axle load
- the speed of the vehicle
- the temperature
- the tyre slip angle and/or the cornering force used (Wabco, 2011).

Maintaining cornering stability is an essential requirement for the steerability of a vehicle. The cornering force coefficient decreases much more rapidly than the brake force coefficient in combination with the same brake slip (Wabco, 2011).

The brake slip is the percentage ratio of vehicle speed to wheel speed (Wabco, 2011).

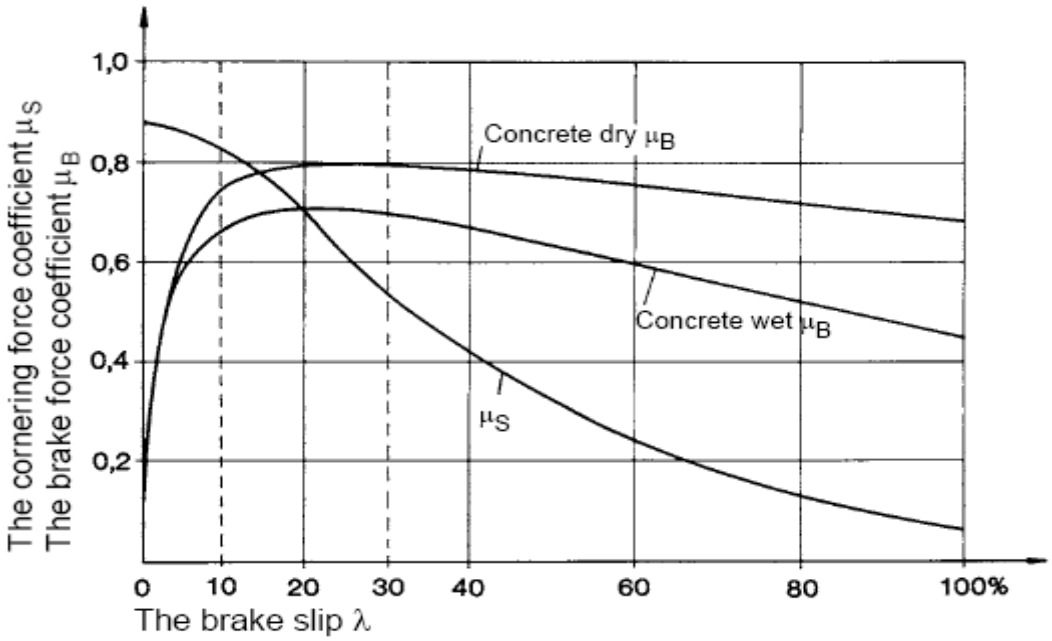
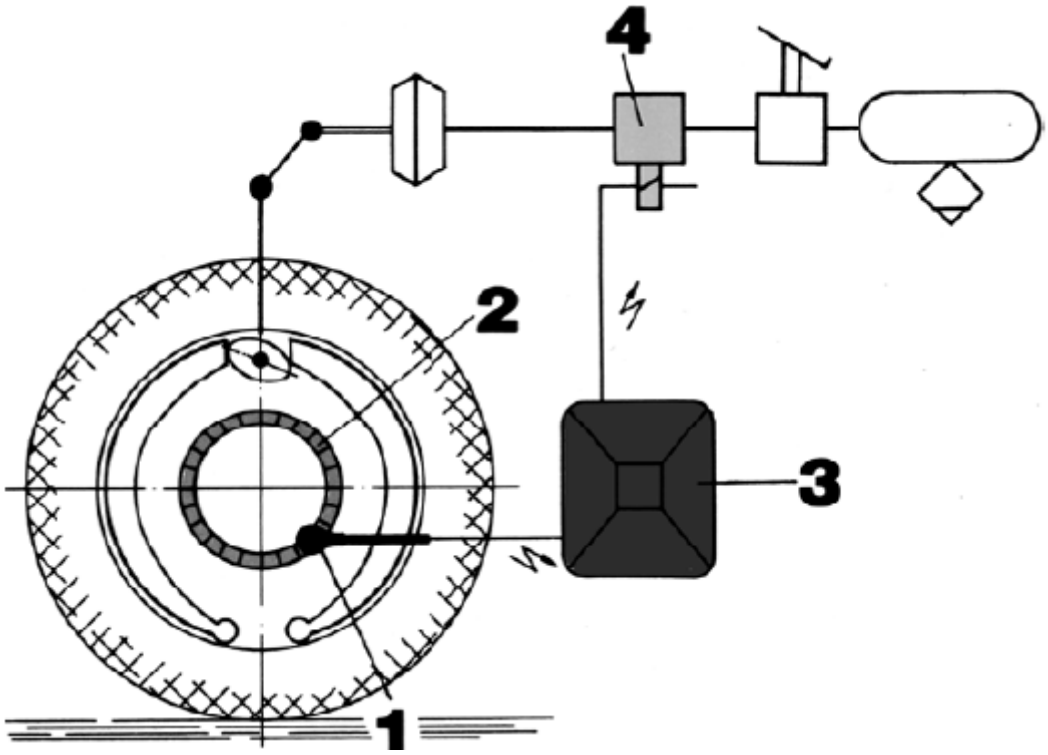


Figure 2.1. Relationship between μ_B, μ_S and λ (Wabco, 2011).

Illustration in Figure 2.1. shows the relationship between the brake force coefficient μ_B, the cornering force coefficient μ_S and the brake slip λ for different road conditions. While maximum adhesion is not achieved, it is possible to increase the braking force within the "stable" range by increasing the slip. In this case, there are also sufficiently large cornering forces available to keep the vehicle steerable and therefore stable. If the unstable range of the $\mu-\lambda$ curve (between approx. 30 and 100%) is reached due excessive braking forces, the wheel is overbraked and will lock (100% slip). The vehicle is then almost completely unsteerable. To prevent this from happening, the ABS system regulates adhesion between 10 % and 30 % slip (Wabco, 2011).

2.2.3. Operation of ABS



1 = sensor, 2 = pole wheel, 3 - electronic control unit, 4 = solenoid valve
Figure 2.2. Structure of the ABS control circuit (Wabco, 2011).

The basic structure of the ABS control circuit is shown in Figure 2.2. The fixed sensor connected to the axle continuously picks up the rotary movement of the

wheel by means of the pole wheel. The electrical pulses generated within the sensor are transmitted to the electronic control unit (ECU) which uses them to compute the wheel speed. At the same time, the ECU uses a certain mode to determine a reference speed that is close to the vehicle speed, which is not actually measured. From all of this information, the ECU continuously computes the wheel acceleration or wheel deceleration and brake slip values. When certain slip values are exceeded, the solenoid control value is actuated. This causes the pressure in the brake cylinder to be limited or reduced, thereby keeping the wheel within its optimum slip range (Wabco, 2011).

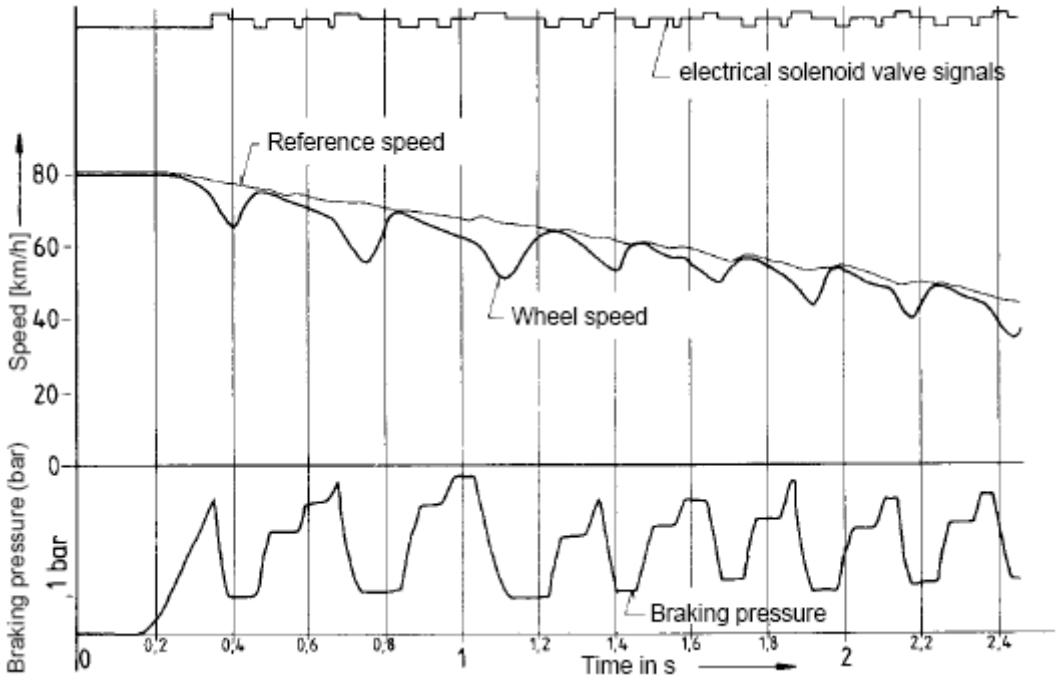


Figure 2.3. Example of an ABS control cycle (Wabco, 2011).

Example of an ABS control cycle is shown in Figure 2.3. The values recorded relate to the control cycle of one wheel. The initial vehicle speed is 80 km/h (Wabco, 2011).

On the abscissa, the control cycles are recorded relative to time. In the area of the ordinate, the braking pressure is shown in the bottom section, and the middle section shows the reference and wheel speeds. The solenoid valve pulses appear in the top section (Wabco, 2011).

The driver actuates the braking system. The brake pressure increases. The speed of the observed wheel suddenly drops much faster than the reference speed. Although the wheel is still within the stable braking range (i.e. between 10 % and 30 % slip), the electronic control unit already starts the control procedure. The ABS solenoid valve is actuated and rapidly reduces the pressure in the brake cylinder of that wheel, and the wheel begins to accelerate again. The electronics cause the solenoid control valve to reverse, keeping the braking pressure at a constant level until the wheel runs within the stable slip range again. As soon as more braking force can be transferred, the braking pressure is increased by means of pulsing - i.e. alternately holding and increasing pressure. If the wheel speed drops significantly relative to the reference speed during this process, a new control cycle begins. This procedure is repeated for as long as the brake pedal is pressed too hard for these road conditions or until the vehicle comes to a halt (Wabco, 2011).

2.3. Anti-Slip Regulation (ASR)

In this section, anti-slip regulation (ASR), theoretical ASR basics and operation of ASR are explained.

2.3.1. ASR

Increasing the engine output (accelerating) on a slippery road surface can easily lead to the maximum adhesion on one or all powered wheels being exceeded causing them to spin, especially if the vehicle is unladen or partially laden. Spinning wheels when driving off or accelerating represent a safety risk just like locked wheel do when braking (Wabco, 2011).

Reasons of the spinning are:

- Wheels that spin transfer just as little cornering force as locked wheels.
- They also no longer transfer any tractive power onto the road (Wabco, 2011).

Consequences of the spinning are:

- Vehicles that do not move or get stuck.
- Vehicles that can no longer be steered, jackknife on uphill gradients, or swerve in corners (Wabco, 2011).

The ASR prevents the powered wheel from spinning and provides the following benefits:

- Tractive power and cornering forces are maintained.
- Stable driving behaviour is ensured when moving off, accelerating and negotiating corners on slippery roads.
- The indicator lamp (if installed) is used to warn the driver about the slippery road conditions.
- Tyre wear is reduced to a minimum, and the motor vehicle's drive train protected.
- The risk of accidents is further reduced (Wabco, 2011).

The ASR represents a worthwhile addition to an ABS-controlled braking system. All that is required to turn ABS control into full ABS/ASR control is an ECU with the additional ASR function and a few additional components for controlling the differential brake and the engine. That is why ASR is only available in combination with ABS. Even a differential lock for off-road use and ASR do not exclude but complement each other (Wabco, 2011).

2.3.2. Theoretical ASR Basics

As with braking, the propulsion force that can be transferred from the tyre onto the road surface depends on the slip between the tyre and the road. Traction slip is the percentage ratio of the wheel speed to the vehicle speed. The traction-adhesion

coefficient and thus the propulsion power depends on the same factors as the braking force coefficient described above (Wabco, 2011).

When the wheels spin heavily (λon = 100%), the adhesion will be reduced significantly below the maximum value. The cornering force coefficient also falls as drive slip increases, and by the time the wheels spin it is negligible (Wabco, 2011).

Drive slip regulators influence the acceleration events only if certain threshold values of the wheel slip or the wheel acceleration are exceeded (Wabco, 2011).

Electronically operated solenoid valves brake the respective wheel proportionally or reduce the engine performance until the stable adhesion range is reached again (Wabco, 2011).

If the event of further regulating action, the wheel is held in the proximity of the maximum possible adhesion within a slip range that is as narrow as possible (Wabco, 2011).

2.3.3. Operation of ASR

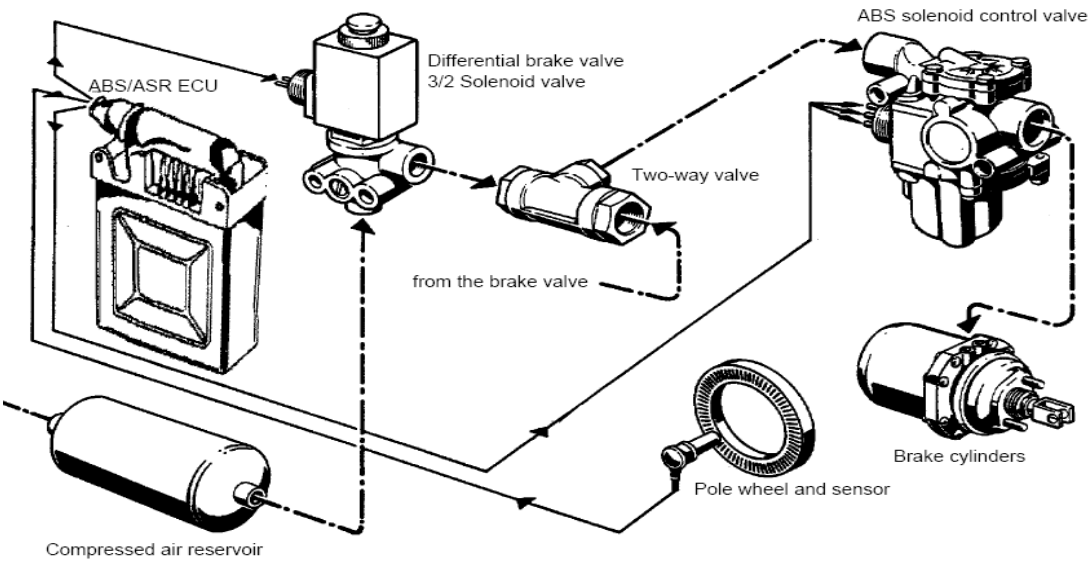


Figure 2.4. Differential brake control (Wabco, 2011).

The differantial brake control is shown in Figure 2.4. Immediately after the ignition has been switched on and the vehicle moves off, the ECU monitors the

rotational behaviour of all wheels above a wheel speed of approx. 2 km/h. The speed and acceleration values of the powered wheels are compared to those of the non-powered wheels (Wabco, 2011).

When a certain difference in speed or slip threshold is exceeded, ASR control sets in. As soon as a driving wheel exceeds the slip threshold as it accelerates, the ECU will actuate the respective differential brake valve and thus control the braking pressure in the applicable brake cylinder of the service brake. The engine's driving torque is now supported on this braked wheel, causing the propulsion power on the other wheel to increase - in much the same way as with engaged differential lock (Wabco, 2011).

As soon as both powered wheels spins or the slip of one spinning wheel has exceeded a threshold value, the system switches from differential brake control engine control, reducing the engine output. Differential brake control is now only used to synchronise the wheels. At a speed above 50 km/h only engine control is now used (Wabco, 2011).

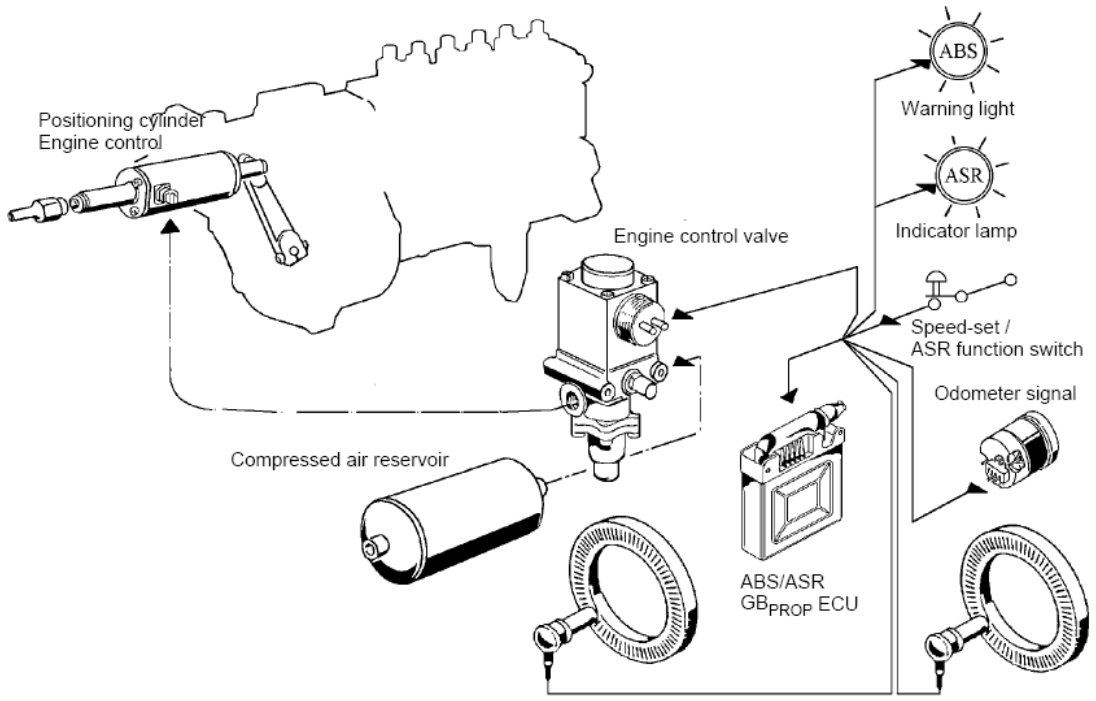


Figure 2.5. Engine control (Wabco, 2011).

The engine control is shown in Figure 2.5. Here the ECU controls the proportional valve which moves the injection pump adjusting lever towards idle position via the ASR positioning cylinder, even if the driver continues to press the accelerator. As soon as values drop below the slip threshold due to the engine's braking effect, the proportional valve exhausts the positioning cylinder again. This causes the engine output to increase again up to the level selected by the driver via the accelerator pedal, or until another speed regulation cycle begins (Wabco, 2011).

This function can also be used as integrated speed limiting (GBProp) and complies with all legal requirements for speed limiting. On wintery roads the coefficients of the friction tend to vary. As a result, engine and differential brake control complement each other. On an even road surface control is mainly implemented by a reduction of the engine speed, and differential brake control is restricted to synchronising the powered wheels. If the friction coefficient differs on either side, the differential brake control is prioritised and applies pressure only the brake cylinder of the spinning wheel. The driving torque is therefore transferred to the other wheel. To avoid overheating the wheel brake, the differential brake threshold value is linearly increased above approx. 35 km/h so that the slip increasingly regulated through the engine speed control. Differential control is no longer initiated at speeds exceeding 50 km/h (Wabco, 2011).

Electronic engine controls are often used in articulated buses but increasingly also for other motor vehicles. The mechanical linkage between the accelerator pedal and the fuel-injection pump is then dispensable apart from a short link between the electrical control motor and the pump adjusting lever. The mechanical linkage is replaced by an electrical setpoint generator on the accelerator pedal (potentiometer) and a control motor fitted close to the fuel-injection pump. The control signal set by the ABS/ASR ECU is then relayed via digital interface to the ECU of the drive-by-wire system which in turn now transmits the corresponding control commands to the control motor (Wabco, 2011).

2.4. Electronically Controlled Brake System (EBS)

In this section, electronically controlled brake system (EBS), system structure in buses, description of the EBS components and description of the EBS control functions are explained.

2.4.1. EBS

The demands on developing braking systems are increasing steadily. Therefore, the development and introduction of an electronic braking system (EBS) is a logical step. EBS increases traffic safety in terms of reduced stopping distance and improved brake stability. The full diagnosis and surveillance functions as well as the display of brake lining wear offer an effective fleet logistics (Wabco, 2003).

Some advantages of EBS are:

- The electronic braking system has a great number of functions. The aim is to maximise the braking safety at reduced costs, for instance by optimising the wheel brake lining wear.
- Setting pressure, based on to wear criteria, to the front and rear axle results in uniform lining wear. Overall wear is minimised by distributing the load on all wheel brakes uniformly. Moreover, servicing and lining replacement are done at the same time and this reduces down-time costs.
- Depending on the vehicle utilisation profile and other factors, this also means considerable savings for the vehicle user. In terms of wheel brake service costs alone, a firsthand owner will save more money with an electronically braked bus than with a vehicle having a conventional braking system (Wabco, 2003).

2.4.2. System Structure in Buses

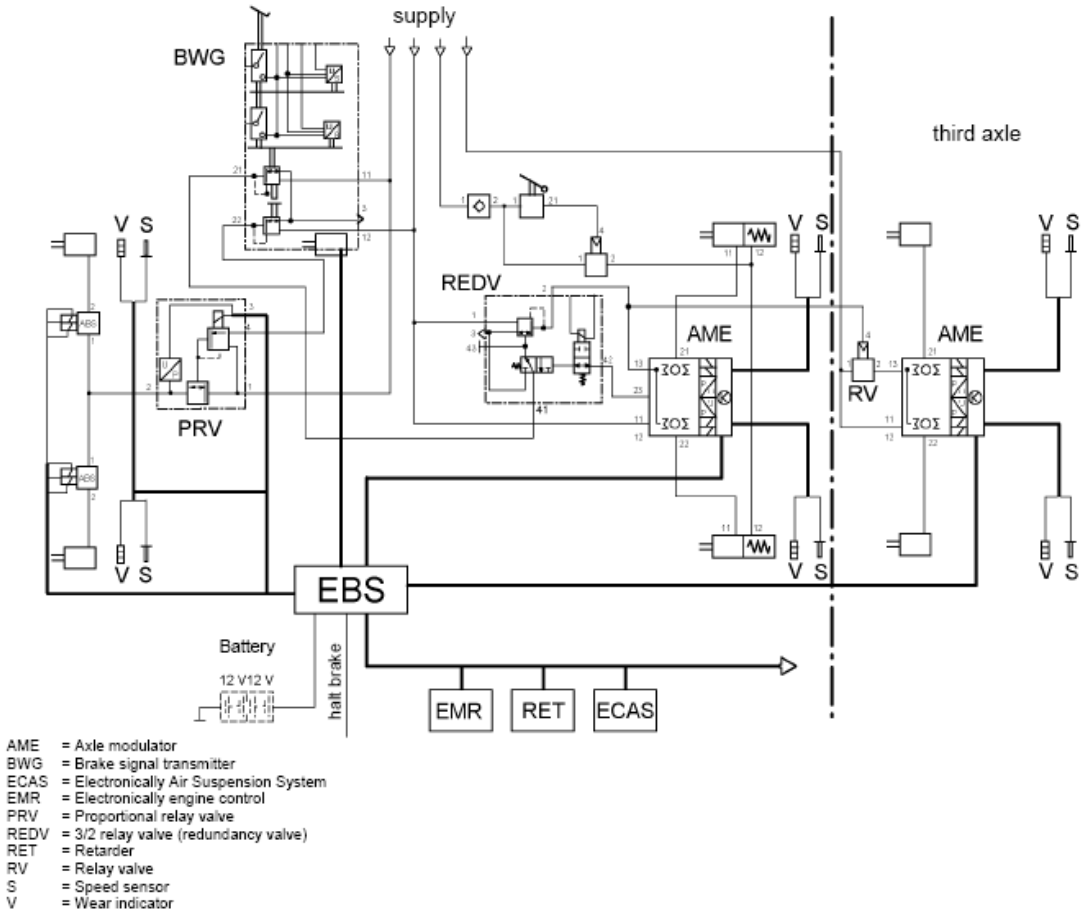


Figure 2.6. 2P/1E EBS system (Wabco, 2003).

The 2P/1E EBS system is shown in Figure 2.6. The EBS described here consists of a dual-circuit, purely pneumatic unit and a superimposed single-circuit, electro-pneumatic unit. This configuration is described as 2P/1E system (Wabco, 2003).

The single-circuit, electro-pneumatic unit comprises a central electronic control device (central module), the axle modulator with integrated electronic unit for the rear axle, and, if necessary, the axle modulator for the third axle, a brake signal transmitter with two integrated desired value sensors and brake switches, as well as a proportional relay valve and two ABS valves for the front axle (Wabco, 2003).

In terms of structure, the dual-circuit pneumatic unit basically corresponds to that of a conventional braking system. This unit serves as redundancy and only becomes active in case of electro-pneumatic circuit failure (Wabco, 2003).

2.4.3. Description of the EBS Components

In this section, brake signal transmitter, EBS central module, proportional relay valve, 3/2 relay valve and axle modulator are explained.

2.4.3.1. Brake Signal Transmitter

Figure 2.7. Brake signal transmitter (Wabco, 2003).

The brake signal transmitter is shown in Figure 2.7. It is used to produce electrical and pneumatic signals, and to increase and decrease the air pressure of the electronically controlled braking system. The device has a dual-circuit pneumatic and a dual-circuit electrical structure. Actuation start is recorded electronically by a double switch. The operating tappet's route is controlled and transmitted as pulse-width modulated electrical signal. Further pneumatic redundancy pressure is delivered in circuits 1 and 2. The pressure in the second circuit is retained slightly in the process. In case of (electrical or pneumatic) failure of a circuit, the other circuits remain functional (Wabco, 2003).

2.4.3.2. EBS Central Module

Figure 2.8. EBS central module (Wabco, 2003).

The EBS central module is shown in Figure 2.8. This module is used to control and monitor the electronically controlled braking system. It determines the vehicle's nominal delay from the signals received by the brake signal transmitter. The nominal delay and the wheel velocity measured by the speed sensors are input signal for the electro-pneumatic control unit, which uses it to calculate nominal pressure values for the front axle and rear axle(s). The front axle's nominal pressure value is then compared with the measured actual value, and any existing deviations corrected with the help of the proportional relay valve. Moreover, the wheel velocity is evaluated so that in case of locking, an ABS control can be carried out by modulating the braking pressure in the brake cylinders. The central module exchanges EBS system bus related data with the axle modulators.

The central module communicates with other systems (engine control unit, retarder, display unit, etc.) via the vehicle data bus in accordance with SAE J 1939 (Wabco, 2003).

2.4.3.3. Proportional Relay Valve

Figure 2.9. Proportional relay valve (Wabco, 2003).

The proportional relay valve is shown in Figure 2.9. This valve is used in the electronically controlled braking system to modulate the braking pressure on the front axle. It comprises the proportional solenoid valve, relay valve and pressure sensor. Electrical drive and monitoring takes place via the central module of the hybrid system (electro-pneumatically / pneumatically).

The control current impressed by the electronic unit is transformed via the proportional solenoid valve into a control pressure for the relay valve. The proportional relay valve's output pressure is proportional to this pressure. The pneumatic drive on the relay valve takes place via the brake signal transmitter's redundant (backup) pressure (Wabco, 2003).

2.4.3.4. 3/2 Relay Valve

Figure 2.10. 3/2 relay valve (Wabco, 2003).

The 3/2 relay valve is shown in Figure 2.10. This valve is used to supply air to and remove air quickly from the brake cylinder on the rear axle in case of redundancy, and comprises several valve units which must fulfil the following functions, among others:

- 2/2 solenoid valve for controlling redundancy in intact electro-pneumatic braking circuit
- Relay valve function, to improve the time behaviour of redundancy
- Pressure retention, to synchronise the beginning of pressure level control on the front and rear axle, in case of redundancy
- In case of redundancy, rear axle 1:1 is controlled.

The 3/2 relay valve also has a 3/2 directional control valve to which current is supplied in case of ABS and is thus meant to prevent an involuntary drive through of the rear axle redundancy pressure during ABS control (Wabco, 2003).

2.4.3.5. Axle Modulator

Figure 2.11. Axle modulator (Wabco, 2003).

The axle modulator is shown in Figure 2.11. This modulator controls the brake cylinder pressure on the two sides of a single or dual axle. It has two pneumatically independent pressure control channels with an air admission and bleeder valve each, individual pressure sensors and a joint electronic control unit.

Desired pressure definition and external surveillance take place via the central module. Moreover, wheel rotation speed is measured and evaluated via two speed sensors. In case of wheel-lock or wheel-spin, the set nominal value is modified. Provision has been made for the connection of two sensors to detect brake lining wear.

The axle modulator for the driving axle has an additional connection for a redundant pneumatic braking circuit. A two-way check valve on each side drives the higher pressure (electro-pneumatic or redundant) through to the brake cylinder. The axle modulator for the additional axle does not have three two-way valve (Wabco, 2003).

2.4.4. Description of the EBS Control Functions

In this section, endurance brake integration, delay control, braking force distribution, brake lining wear control, anti-lock braking system, traction control system and drag torque control are explained.

2.4.4.1. Endurance Brake Integration

The braking system has an integrated brake management function which always regulates the endurance brake when the brake pedal is activated based on an optimum delay of the vehicle. Optimum service brake wear is attained through the distribution of endurance and service brake. This function is an important part of delay control. The integration of endurance brake can be deactivated via the switch (Wabco, 2003).

2.4.4.2. Delay Control

Delay control is used to adapt the braking pressure level to the driver's desired braking rate. When the same amount of pressure is applied on the pedal, the vehicle is often braked in the same manner, irrespective of the amount of load it is

carrying. If the coefficient of friction on a wheel brake changes (for instance when the vehicle is moving downhill), the delay control unit ends every adaptation process when a predefined, fixed maximum is attained, to enable the driver to also to feel the deterioration.

Adapting to the braking system hysteresis is also part of delay control. Each time the brake is released, the releasing process is chosen in such a way that an immediate braking force modification is adjusted. This function results in quick release of the brakes, i.e. car feeling (Wabco, 2003).

2.4.4.3. Braking Force Distribution

The distribution of braking forces on the front and rear axles depends, among others, on the comparison made in the program range “Delay control” between the actual and nominal value of vehicle delay. The pressure on the front and rear axles is set in such a way that there is optimum braking pressure output on these axles (Wabco, 2003).

2.4.4.4. Brake Lining Wear Control

When the brake is applied partially, the braking pressure distribution is adjusted, notwithstanding the available wear signals, i.e. the detected wear difference. The pressure on the wheel brakes with more lining wear is reduced slightly, whereas the pressure on the wheel brakes with less lining wear is increased adequately, so that there is no change in the overall braking rate required by the driver (Wabco, 2003).

2.4.4.5. Anti-Lock Braking System (ABS)

The control logic determines from the wheel rotation speed whether one or more wheels can be blocked and decides whether to decrease, maintain, or increase

the braking pressure on it. The rear axle wheels are controlled in their optimum area in a similar manner.

On roads with extremely different adhesion levels between the right and left sides, vehicles are uncontrollable or difficult to control using the different braking forces in ABS. As a result, the braking pressure on the front axle brakes is not adjusted independent of each other, so that the driver can have a steering reaction. If the driving wheels are locked when the endurance brake is applied on low adhesion levels, possibly resulting in vehicle instability, the ABS endurance brake is deactivated via the vehicle's CAN bus to maintain vehicle stability (Wabco, 2003).

2.4.4.6. Traction Control System (TCS)

Just like in the ABS function, while the vehicle is in motion, the electronic control system determines whether the wheels are in the stable area of the μ slip curve. In case of wheel-spin, the engine output and/or driving axle wheel braking is adjusted by the axle modulator via the CAN bus and engine control system. An activated traction control system is displayed on the functions display (Wabco, 2003).

2.4.4.7. Drag Torque Control

Drag torque occurs in the drive train due to actuation or change of gas. The resultant braking torque can lead to driving wheel locking and thus to vehicle instability. Drag torque control prevents this situation. When a slip state is exceeded, the engine torque increases and the brake torque is reduced, irrespective of the driving wheel velocity. The function of the traction control system ends when the driving wheel values become stable again (Wabco, 2003).

3. COMMERCIAL VEHICLE CONTROL SYSTEM

In this chapter, vehicle electronic control system and CAN communication protocol are presented.

3.1. Vehicle Electronic Control System

Vehicle electronic control system is used to control the all inputs/outputs of the vehicle functions and to warn the user by checking the system faults. The vehicle has a central computer called ZR-32 in this study case. This computer has multiplexer nodes that have multiple inputs and outputs. It has also CAN bus connectors to connect the powertrain systems and instrumentation systems.

Multiplex control system is a PLC (Programmable Logic Controller) application that consists of one body controller (ZR-32), one or more input output module (CAN Multiplexer). In Figure 3.1, block diagram of the multiplex system is shown.

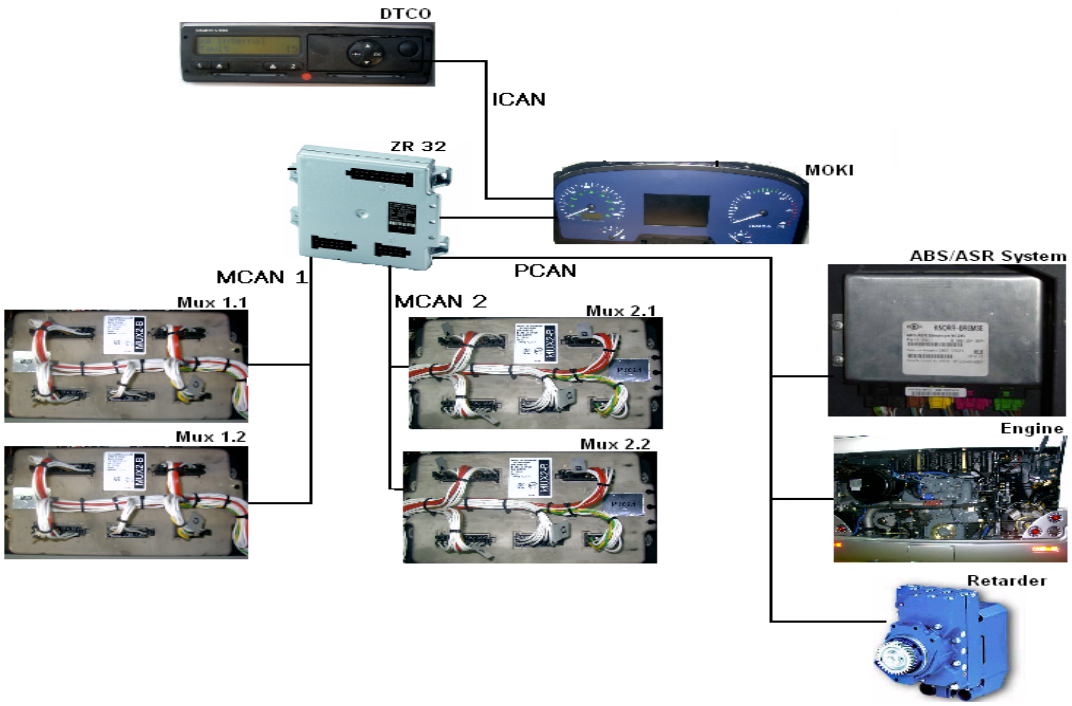


Figure 3.1. Block Diagram of the Multiplex System

PCAN (Powertrain CAN) is a CAN based communication network on the buses. This CAN line makes connection between engine control unit, transmission control unit, and brake systems. It is based on SAE J1939 communication protocol with 250kbyte/s communication speed.

ICAN (Instrumentation CAN) is also a CAN communication between body controller, instrument panel and tachograph. Its communication speed is 250kbyte/s.

MCAN (Multiplexer CAN) is CAN based communication line; its speed is 125kbyte/s, among body controller and I/O multiplexers. Body controller controls a multiplexer. Its basic function is to sense the digital inputs and outputs on the vehicle. The multiplexer has 24 digital inputs, 6 analog inputs, and 32 digital outputs and a CAN connection input. CAN connection is based on ISO 11898 standard.

The basic system of the vehicle electronic system is the body controller. This controller executes an application software called as LogiCAD. This is a Windows based PLC software. It is developed on IEC 61113-3 visual programming language.

3.2. CAN Communication Protocol

The Controller Area Network (CAN) Protocol was developed by Robert Bosch in 1982. Over the last 22 years CAN communication has become a standard for automotive networking and has a wide uptake in non-automotive systems where it is required to network together a few embedded nodes.

CAN communication has many attractive features for the embedded developer. It is a low-cost, easy-to-implement, peer to peer network with powerful error checking and a high transmission rate up to 1 Mbit/sec. Each CAN packet is quite short and may hold a maximum of eight bytes of data. This makes CAN suitable for small-embedded networks, which have to reliably transfer small amounts of critical data between nodes (Hitex, 2005).

3.2.1. CAN Node

Below, a general CAN node is shown below in Figure 3.2. Each CAN node consists of a controller and a separate CAN controller. The CAN controller may, as in the case of the microcontroller or it may be a stand alone controller in a separate chip to the microcontroller. The CAN controller is interfaced to the twisted pair by a line driver and the twisted pair is terminated at either end by a 120 Ohm resistor. The most common mistake with a first CAN network is to forget the terminating resistors and then nothing works (Hitex, 2005).

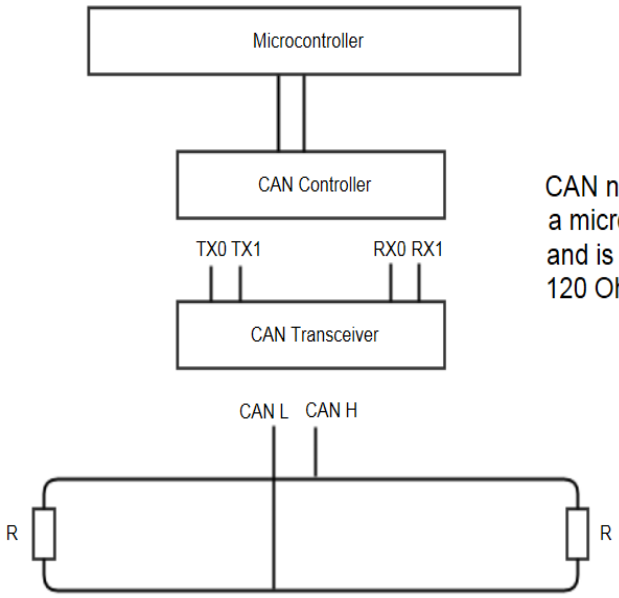


Figure 3.2. The Diagram of Typical CAN nodes (Hitex, 2005).

The CAN controller has a physical layer device called as receiver. So, as the node wiring on to the bus, it is also listening back at the same time. This is the basis of the message arbitration and for some of the error detection.

The two logic levels are written onto the twisted pair as follows, a logic one is represented by bus idle with both wires held half way between 0 and $V_{CC.}$ A logic zero is represented by both wires being differentially driven. The Logical representation of the CAN bus is shown in Figure 3.3. (Hitex, 2005).

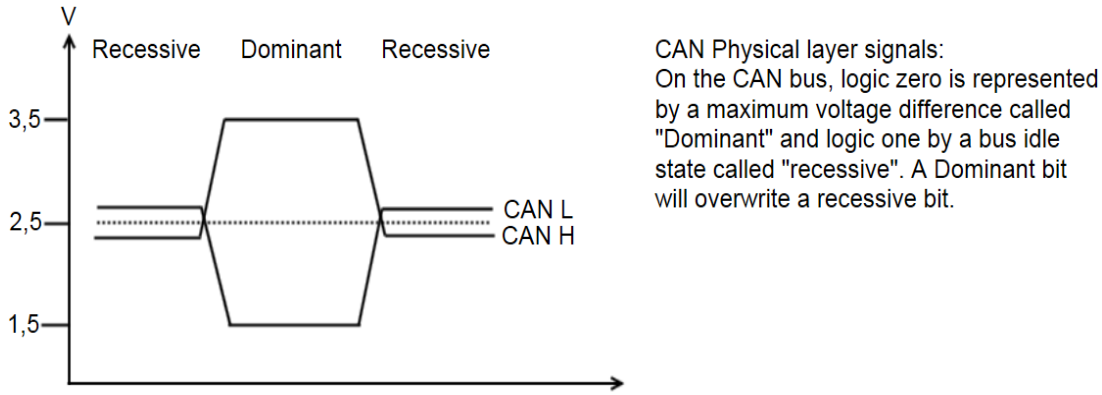


Figure 3.3. The Logical representation of the CAN bus (Hitex, 2005).

In “CAN speak” logic one is called a recessive bit and a logic zero is called a dominant bit. In all cases a dominant bit will overwrite a recessive bit. So, if ten nodes write recessive and one writes dominant, then each node will read back a dominant bit. The CAN bus can achieve bit rates up to a maximum of 1Mbit/sec. typically this can be achieved over about 40 metres of cable. By dropping the bit rate, longer cable runs may be achieved. In practice 1500 metres cable can be used with the standard drivers at 10kbit/sec. (Hitex, 2005).

4. INTELLIGENT SAFETY PACKAGE SOFTWARE

In this chapter, automatic park brake, halt brake and hill holder approach are presented.

4.1. Automatic Park Brake Approach

In the literature about automatic park brake, which is one of the safety package functions are investigated, following applications are faced. In one reference of these studies, automatic park brake becomes active if it is determined by sensor which is placed in driver seat that the driver isn't on the driver seat, the driver doesn't activate the park brake and the door is open. In another reference study, the automatic park brake becomes active if the door is locked and the driver doesn't activate the park brake. The deficiency of these studies is leaving the safety partially to the driver hands. It should be noted that, the driver can forget locking the door as activating park brake or the driver can close the door by reflex when forgets activating park brake. In some reference studies, automatic park brake becomes active when the driver turns off the ignition. But, while driving the vehicle, many special situations can occur. For example, a driver can need to restart the engine that is stopped suddenly while driving with a certain speed or a driver can need to move the vehicle by pushing when the vehicle has engine error. In such situations, existing studies are unable to yield the desired results. Therefore, automatic park brake becomes active after checking vehicle speed when the driver turns off the ignition in new designed software. In this study, the driver can cancel automatic park brake with a sealed switch when the driver needs to move the vehicle by pushing. When the conditions to cancel automatic park brake are investigated, it is realized that the new designed automatic park brake shouldn't be cancelled without pushing throttle pedal when the vehicle starts running to prevent vehicle movement if the vehicle is parked on a hill. Input-Output list of the new designed automatic park brake system is given in Table 4.1.

Table 4.1. Input-Output list of Automatic Park Brake System

INPUTS	OUTPUTS
Ignition signal	Automatic park brake valve output
Vehicle speed signal	Wake up signal of body controller
Sealed switch signal	
Engine running signal	
Throttle pedal percentage	
Park brake signal	

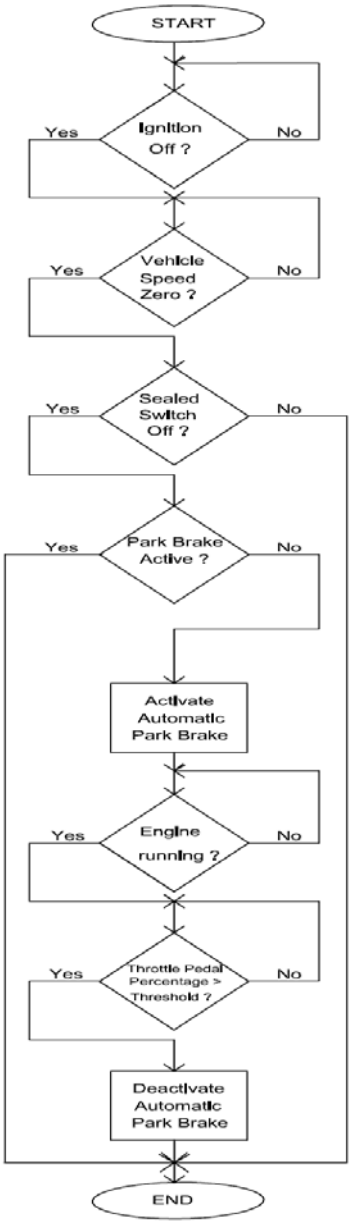


Figure 4.1. Flowchart of Automatic Park Brake Function

Automatic park brake system is designed as shown in Figure 4.1. Ignition signal, vehicle speed signal, sealed switch signal and park brake signal are checked to activate the automatic park brake function. If the ignition is off, vehicle speed is zero, sealed switch is off and park brake is deactive, then the automatic park brake will be activated. Primarily, multiplex system of the vehicle must be awakened during the demand of automatic park brake to be able to activate automatic park brake function. Then, the necessary signal for the automatic park brake valve, which will be added to air line of park brake, will be activated via appropriate multiplexer output. Whereby, the necessary braking of automatic park brake will be applied to the vehicle. Engine running signal and throttle pedal percentage are checked to deactivate automatic park brake function. While automatic park brake function is active, if engine restart and throttle pedal percentage is bigger than defined threshold value (Threshold value is chosen as %10), automatic park brake function will be deactivated by deactivating automatic park brake valve output.

4.2. Halt Brake Approach

Halt brake system which is one of safety package functions is activated while passengers are getting in or out from the vehicle at bus stations and guarantee to block vehicle movement until doors are closed and passengers are transferred safely. Articulation system ECU (Electronic Control Unit) releases an interlock signal in dangerous situations and bus manufacturers must stop the vehicle completely when this signal is released. Therefore, the halt brake function is activated to fulfill this requirement. When articulation system ECU releases interlock signal, halt brake function will be activated and the vehicle will be stopped completely. Working conditions of the halt brake function are interpreted and new algorithm is designed as introduced below. Input-Output list of the new designed halt brake system is given in Table 4.2.

Table 4.2. Input-Output list of Halt Brake System

INPUTS	OUTPUTS
Doors open/close signal	Halt brake output for EBS ECU
Halt brake enable switch signal	
Vehicle speed signal	
Handicapped passenger lift open/close signal	
Park brake signal	
Throttle pedal percentage	
Articulation system ECU interlock signal	

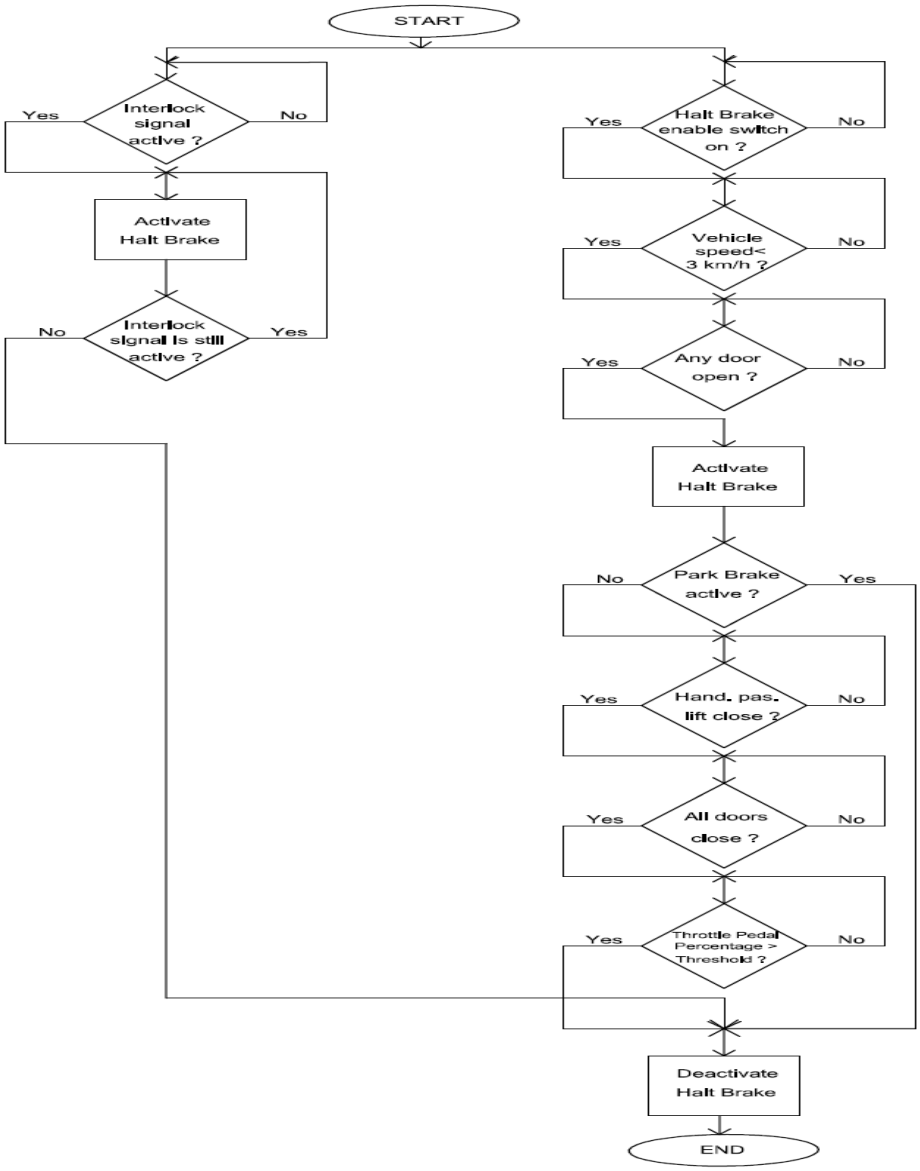


Figure 4.2. Flowchart of Halt Brake Function

Halt brake system is designed as shown in Figure 4.2. Halt brake function can be activated by two ways. When the vehicle is in reverse gear and articulation system ECU releases interlock signal, then the function will be activated regardless of anything else and won't be deactivated unless the articulation system ECU stops releasing interlock signal. The halt brake function will be deactivated as soon as articulation system ECU stops releasing interlock signal. A further way for activating the halt brake function, halt brake enable switch signal, vehicle speed signal and doors open/close signal are checked. If halt brake enable switch is on, vehicle speed is under 3 km/h and any door of the vehicle is open, then halt brake will be activated. Park brake signal, handicapped passenger lift close signal, doors open/close signal and throttle pedal percentage are checked to deactivate the halt brake function. While the halt brake function is active, if park brake becomes active or handicapped passenger lift is closed, all doors are closed and throttle pedal percentage is bigger than the defined threshold value (Threshold value is chosen as %10), the halt brake function will be deactivated.

4.3. Hill-Holder Approach

In this section, hill-holder function, external brake request messages and vehicle dynamics for hill-holder function are introduced.

4.3.1. Hill-Holder Function

Majority of the existing studies activate the hill holder function by using a solenoid valve which is activated with a signal that comes from body controller. Existing brake companies also activate hill holder function via a proportional valve which controls service brakes. But, existing brake companies don't evaluate weight of the vehicle and slope of the road, so they couldn't make a sensitive calculation. As a result, during a hill start, these systems cause an uncomfortable start. Developed system is controlled by LogiCAD based PLC software. Developed system is also evaluate tilt and pressure sensors data to provide safe and comfortable start without

rolling backwards by activating service brakes under right conditions and timing. External brake request feature of the main brake system is used to activate or deactivate appropriate brake force when needed. Proportional brake force is adjusted with external brake request feature via CAN messages EBC1, EBC5 and XBR. Hill holder function can be activated when the vehicle is in reverse gear with the developed system and remains active until necessary conditions exist to deactivate the hill holder function independent of time. Developed system works parallel to existing brake system. In this way, stability of existing system is protected. Input-Output list of the new designed hill holder system is given in Table 4.3.

Table 4.3. Input-Output list of Hill-Holder System

INPUTS	**OUTPUTS**	
Tilt sensor signal	EBC 1 message	SA of controlling device for brake control
Pressure sensor signal	EBC 5 message	Foundation brake use
Current gear message		XBR system state
Throttle pedal percentage		XBR active control mode
		XBR acceleration limit
	XBR message	External acceleration demand
		XBR EBI mode
		XBR priority
		XBR control mode
		XBR message counter
		XBR message checksum

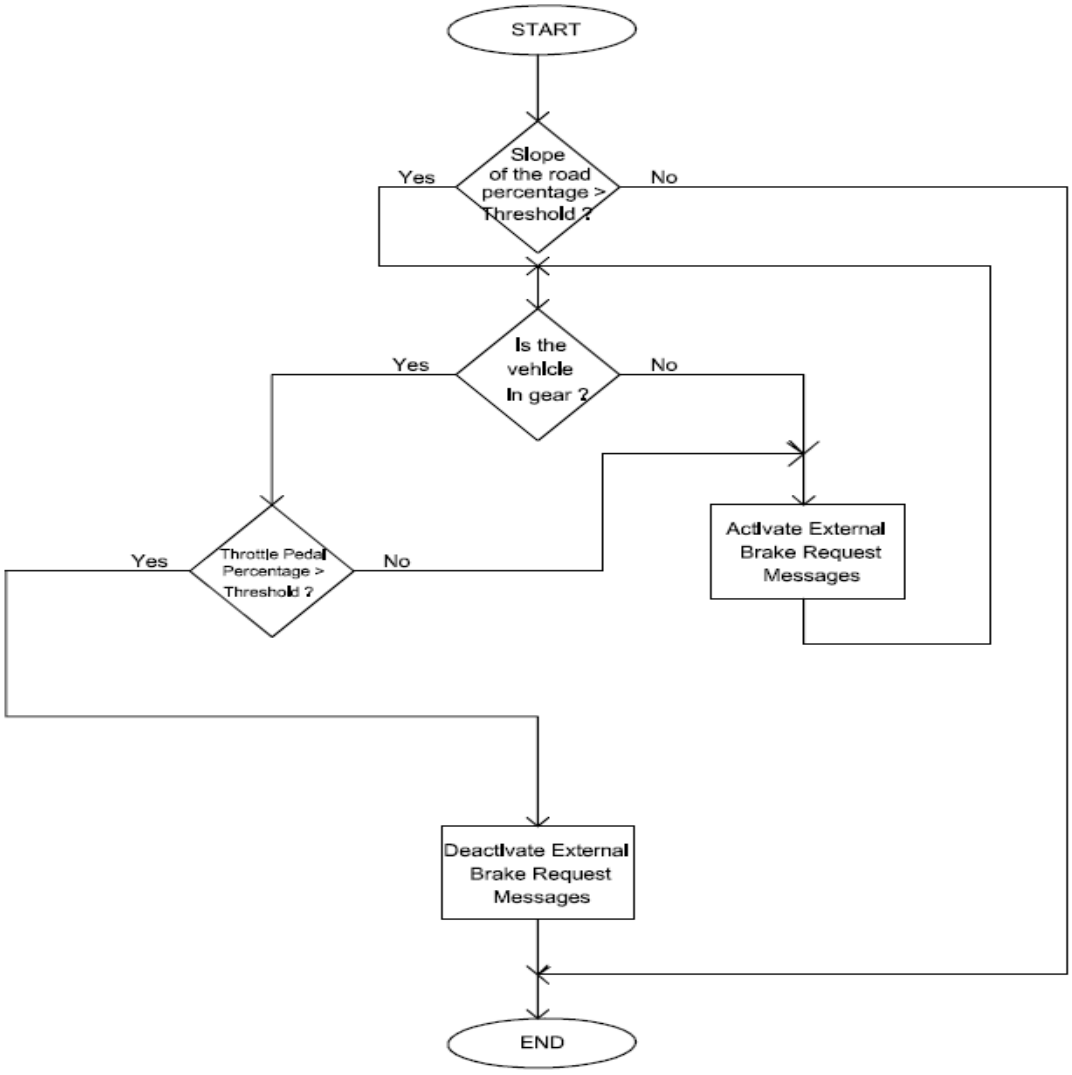


Figure 4.3. Flowchart of Hill-Holder Function

Hill holder system is designed as shown in Figure 4.3. Primarily, data from tilt sensor is evaluated by hill holder system. If slope of the road is greater than the defined threshold value (Threshold value is chosen as %5), then the system checks if the vehicle is in gear or not. If slope of the road is greater than the defined threshold value and the vehicle isn't in gear, hill holder system is activated proportionally via external brake request messages. Tilt sensor and pressure sensors data are evaluated while calculating proportional brake force with external brake request messages. Current gear message and throttle pedal percentage are checked to deactivate the hill holder function. While the hill holder function is active, if the vehicle is in gear (included reverse gear) and throttle pedal percentage is greater than defined threshold

value (Threshold value is chosen as %10), hill holder function will be deactivated proportionally via external brake request messages. When throttle pedal percentage becomes %10, applied brake force starts to decrease and when throttle pedal percentage becomes %33, applied brake force becomes zero.

According to a statistic which is made by T.C.K. General Directorship, maximum slope of the road is declared as %10 at highways, %15 at urban roads and %22 at rural roads. It can be increased up to %30 around the world.

4.3.2. External Brake Request Messages

EBC 1 – Source Address of Controlling Device for Brake Control:

EBS ECU releases address information of the ECU which sends external brake request to EBS according to SAE J1939 standard via this message. Details of this message is given in Table 4.4.

Table 4.4. EBC 1 – Source Address of Controlling Device for Brake Control

ID	18F0010B
Transmission Repetition	100 ms
Byte	7
Bit	1 - 8
Data Length	1 Byte
Resolution	1 sa/bit, 0 offset
Data Range	0 - 255
Operational Range	0 - 253

EBC 5 – Foundation Brake Use:

EBS ECU releases the situation of brakes via this message. Details of this message is given in Table 4.5.

Table 4.5. EBC 5 – Foundation Brake Use

ID	18FDC40B	Coding	Definition
Transmission Repetition	100 ms	00	Foundation brakes not in use
Byte	2	01	Foundation brakes in use
Bit	1 - 2	10	Reserved
Data Length	2 Bit	11	Not available
Data Range	0 - 3		

EBC 5 – XBR System State:

EBS ECU releases the information about what kind of external brake request is accepted via this message. Details of this message is given in Table 4.6.

Table 4.6. EBC 5 – XBR System State

ID	18FDC40B	Coding	Definition
Transmission Repetition	100 ms	00	Any external brake demand will be accepted
Byte	2	01	Only XBR of highest priority will be accepted
Bit	3 - 4	10	No external brake demand will be accepted
Data Length	2 Bit	11	Not available
Data Range	0 - 3		

EBC 5 – XBR Active Control Mode:

EBS ECU releases the information about what kind of external brake request is executed via this message. Details of this message is given in Table 4.7.

Table 4.7. EBC 5 – XBR Active Control Mode

ID	18FDC40B	Coding	Definition
Transmission Repetition	100 ms	0000	No brake demand being executed
Byte	2	0001	Driver's brake demand being executed
Bit	5 - 8	0010	Addition Mode
Data Length	4 Bit	0011	Maximum Mode
Data Range	0 - 15	0100 - 1110	Reserved
		1111	Not available

EBC 5 – XBR Acceleration Limit:

Main brake system can limit temporarily or permanently maximum braking performance of external brake systems. Due to high brake temperature, main brake system can need temporary limitation or bus manufacturers can determine a general limitation for external brake systems. EBS ECU releases the limitation of external brake systems via this message. Details of this message is given in Table 4.8.

Table 4.8. EBC 5 – XBR Acceleration Limit

ID	18FDC40B
Transmission Repetition	100 ms
Byte	3
Bit	1 - 8
Data Length	1 Byte
Resolution	0.1 m/s² per bit, -12.5 m/s² offset
Data Range	-12.5 m/s² , +12.5 m/s²
Operational Range	-10 m/s² , +10 m/s²

XBR – External Acceleration Demand:

This message is released by external brake systems and specify the acceleration value which is expected to be taken by main brake system. Details of this message is given in Table 4.9.

Table 4.9. XBR – External Acceleration Demand

ID	0C040B21
Transmission Repetition	20 ms active, 200 ms passive
Byte	1,2
Bit	1 - 16
Data Length	2 Byte
Resolution	1/2048 m/s² per bit, -15.687 m/s² offset
Data Range	-15.687m/s² , +15.687 m/s²
Operational Range	-10 m/s² , +10 m/s²

XBR – XBR EBI (Endurance Brake Integration) Mode:

This message is released by external brake systems and specify if auxiliary brake systems such as retarder or engine brake will be used or not during external brake request. Details of this message is given in Table 4.10.

Table 4.10. XBR – XBR EBI Mode

ID	0C040B21	Coding	Definition
Transmission Repetition	20 ms active, 200 ms passive	00	No endurance brake allowed
Byte	3	01	Only endurance brake allowed
Bit	1 - 2	10	Endurance brake integration allowed
Data Length	2 Bit	11	Not defined
Data Range	0 - 3		

XBR – XBR Priority:

This message is released by external brake systems and specify priority of the external brake request to main brake system. Details of this message is given in Table 4.11.

Table 4.11. XBR – XBR Priority

ID	0C040B21	Coding	Definition
Transmission Repetition	20 ms active, 200 ms passive	00	Highest priority
Byte	3	01	High priority
Bit	3 - 4	10	Medium priority
Data Length	2 Bit	11	Low priority
Data Range	0 - 3		

XBR – XBR Control Mode:

This message is released by external brake systems and specify the control method of external brake request to main brake system. Existing external brake request can be cancelled, total brake request can be calculated by adding external brake request and driver demand (brake signal transmitter) with “Addition Mode” control method or total brake request can be calculated by choosing maximum value

of external brake request or driver demand with “Maximum Mode” control method via this message. The externally initiated brake procedure will be stopped after the XBR control mode switches back to “override disabled”. Details of this message is given in Table 4.12.

Table 4.12. XBR – XBR Control Mode

ID	0C040B21	Coding	Definition
Transmission Repetition	20 ms active, 200 ms passive	00	Override disabled
Byte	3	01	Addition Mode
Bit	5 - 6	10	Maximum Mode
Data Length	2 Bit	11	Not defined
Data Range	0 - 3		

XBR – XBR Message Counter:

This message is to verify the signal path from the demanding device to the brake controller on electronic brake systems. The support of this parameter is mandatory. The initial value of the 4 bit message counter for the first message during a driving cycle is arbitrary. In every following message the counter is incremented by 1 (0 follows 15). Details of this message is given in Table 4.13. (SAE J1939-71, 2004).

Table 4.13. XBR – XBR Message Counter

ID	0C040B21
Transmission Repetition	20 ms active, 200 ms passive
Byte	8
Bit	1 - 4
Data Length	4 Bit
Resolution	1 count/bit, 0 offset
Data Range	0 - 15

XBR – XBR Message Checksum:

The XBR message checksum is used to verify the signal path from the demanding device to the brake controller on electronic brake systems. The support of this parameter is mandatory.

The 4 bit checksum is the sum of the high nibble and the low nibble of the sum of the identifier, the first 7 data bytes and the 4 bit message counter. It is calculated as follows:

Checksum = (Byte1 + Byte2 + Byte3 + Byte4 + Byte5 + Byte6 + Byte7 + message counter&0x0F + message ID low byte + message ID mid low byte + message ID mid high byte + message ID high byte)

Checksum = ((Checksum >> 4) + Checksum) & 0x0F

A failure in the communication sets the XBR system state:

- to 01 (Only XBR of highest priority will be accepted) for failed XBR priority 01 (high priority), 10 (medium priority) or 11 (low priority) messages
- to 10 (no external brake demand will be accepted) for failed XBR priority 00 (highest priority) messages (SAE J1939-71, 2004).

  Details of this message is given in Table 4.14.

Table 4.14. XBR – XBR Message Checksum

ID	0C040B21
Transmission Repetition	20 ms active, 200 ms passive
Byte	8
Bit	5 - 8
Data Length	4 Bit
Resolution	1 count/bit, 0 offset
Data Range	0 - 15

4.3.3. Vehicle Dynamics for Hill-Holder Function

Vehicle dynamics consists of air resistance, rolling resistance, gradient resistance and inertia resistance.

4.3.3.1. Air Resistance (R_L)

The force applied by the air is in the opposite direction while the the vehicle is moving. It is proportional to the the front area and speed of the vehicle. It is shown as $\mathbf{R_L}$.

$$R_L = 0.5 * p * C_W * A * (V_0 + V)^2 \quad (4.1.)$$

p: the density of air (equal to about 1.293 kg/m^3).
C_W: coefficient of air resistance (0,6 - 0,7 for buses).
A: Front area
$\mathbf{V_0}$: Wind velocity (m/s)
V: Vehicle velocity (m/s)

4.3.3.2. Rolling Resistance ($\mathbf{R_{RO}}$)

When a vehicle rolls, it rolls with its tires in contact with the road surface. The relative motion of two hard surfaces produces a friction. Further, neither the road, nor the tire are perfectly rigid. Hence, both flex under the load slightly. As there is a gradual deformation at the contact between the road and the tire, greatest at the bottom most point and least at the entry and exit points, the slip of the tire with respect to the road produces another type of loss of energy which results in a resistance.

$$R_{RO} = G * f_{RO} \quad (4.2.)$$

f_{RO} : $0.01 * (1 + \frac{V}{160})$
G: Vehicle weight
f_{RO}: Rolling resistance coefficient

4.3.3.3. Gradient Resistance (R_e)

When the vehicle moves uphill, a component of its weight works in a direction opposite to its motion. If some energy is not supplied to overcome this backward force, then the vehicle would slow down, stall and roll backwards. If the vehicle travels uphill, then the weight of the vehicle has two components; one perpendicular to the road surface and the other along the road surface. The component along the road surface is the one that tries to restrict the motion.

$$R_e = G * \sin \alpha \quad (4.3.)$$

G: Vehicle weight
α: Slope of the road

4.3.3.4. Inertia Resistance (R_a)

Inertia describes a body's resistance to forces. It determines how much force is necessary to accelerate the body by a certain amount.

$$R_a = m * a \quad (4.4.)$$

m: Vehicle mass
a: Vehicle acceleration

4.3.3.5. Calculating Brake Force for Hill-Holder Function

Hill holder function is activated when the vehicle is standstill, so the vehicle speed is taken 0 km/h while calculating brake force for the hill holder function. Thus, inertia resistance for calculating brake force is taken as zero. Air resistance and rolling resistance values are too small when we compare them with gradient resistance. So, we ignore inertia resistance, air resistance and rolling resistance

values for calculating appropriate brake force. These resistances are used at high speeds for fuel consumption and can be ignored at low speeds.

A tilt sensor which is a sensitive and fast measurement tool is used to calculate tilt data is one of necessary parameters for safety package software to determine if the vehicle is on the hill or not. The data from pressure sensors that are placed to vehicle blowers are calculated and the weight of the gravity center is determined for one of another necessary parameters for safety package software. Data from these sensors are gathered on Multiplexer (MUX) module and transferred to vehicle control unit ZR-32.

Only gradient resistance is considered to calculate appropriate brake force for hill holder function. When throttle pedal percentage becomes %10, applied brake force starts to decrease and when throttle pedal percentage becomes %33, applied brake force becomes zero.

5. SIMULATION AND IMPLEMENTATION

In this chapter, driveline tools of the Matlab Simulink, simulation on the Matlab Simulink, simulation and implementation results are presented.

5.1. Driveline Tools of the Matlab Simulink

The driveline tools of the Matlab Simulink is used to desing hill holder system such as generic engine, vehicle body, tires, differantial, torque converter, gearbox etc.

5.1.1. Generic Engine

The generic engine block models the torque-speed or, equivalently, the power-speed characteristics of an internal combustion engine. Generic engine model is shown below in Figure 5.1.

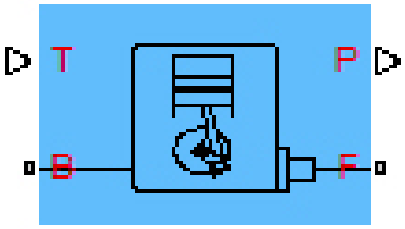


Figure 5.1. Generic Engine

Port T is specified the throttle control as a physical input signal. This signal specifies the engine torque as a fraction of the maximum torque possible in a steady state at a fixed engine speed. The signal must lie between zero and one. The block computes the generated engine power as a physical output signal at port P. B and F are rotational conserving ports representing, respectively, the engine block and the engine crankshaft.

The engine model is specified by an engine power demand function g(Ω). The function provides the maximum power available for a given engine speed Ω.

The block parameters (maximum power, speed at maximum power, and maximum speed) normalize this function to physical maximum torque and speed values.

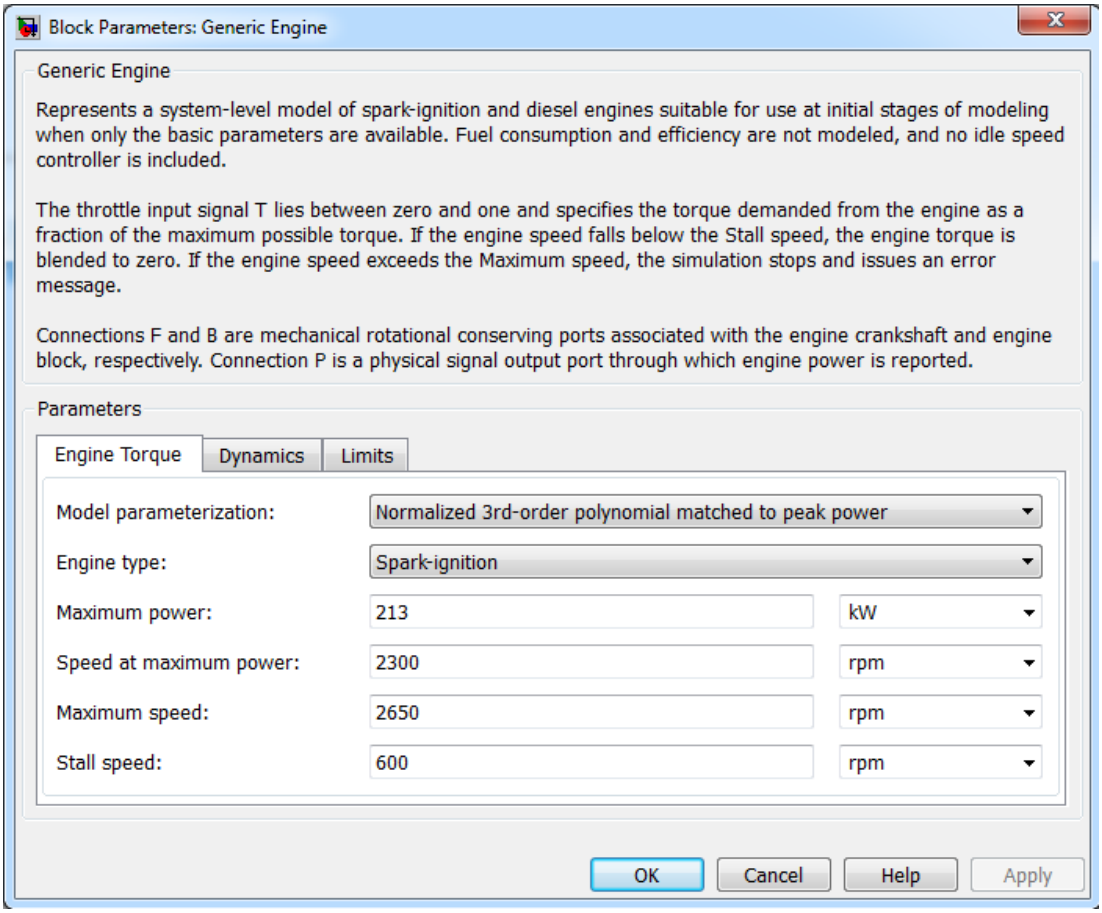


Figure 5.2. Generic Engine Parameters

It was chosen maximum power 213 kW, speed at maximum power 2300 rpm, maximum speed 2650 rpm and stall speed 600 rpm as features of engine.

5.1.2. Vehicle Body

The vehicle body block models a two-axle vehicle, with an equal number of equally sized wheels on each axle, moving forward or backward along its longitudinal axis. The model includes the following vehicle properties:

- Mass

- Number of wheels per axle
- Position of the vehicle's center of gravity (CG) relative to the front and rear axles and to the ground
- Effective frontal cross-sectional area
- Aerodynamic drag coefficient
- Initial longitudinal velocity

Vehicle body model is shown below in Figure 5.3.

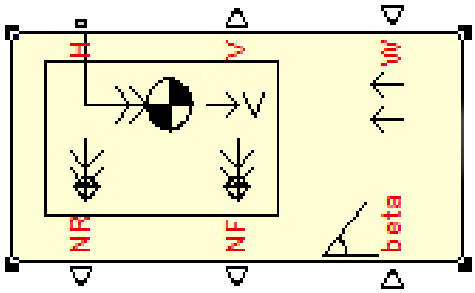


Figure 5.3. Vehicle Body

The headwind speed is specified as W (in meters/second) and the road inclination angle is specified as β (in radians) through physical signal inputs at ports W and beta, respectively. The block reports the longitudinal vehicle velocity V_x and the front and rear normal forces (load on wheels) F_{zf}, F_{zr} as physical signal outputs at ports V, NF, and NR, respectively. The horizontal motion of the vehicle is represented by the translational conserving port H.

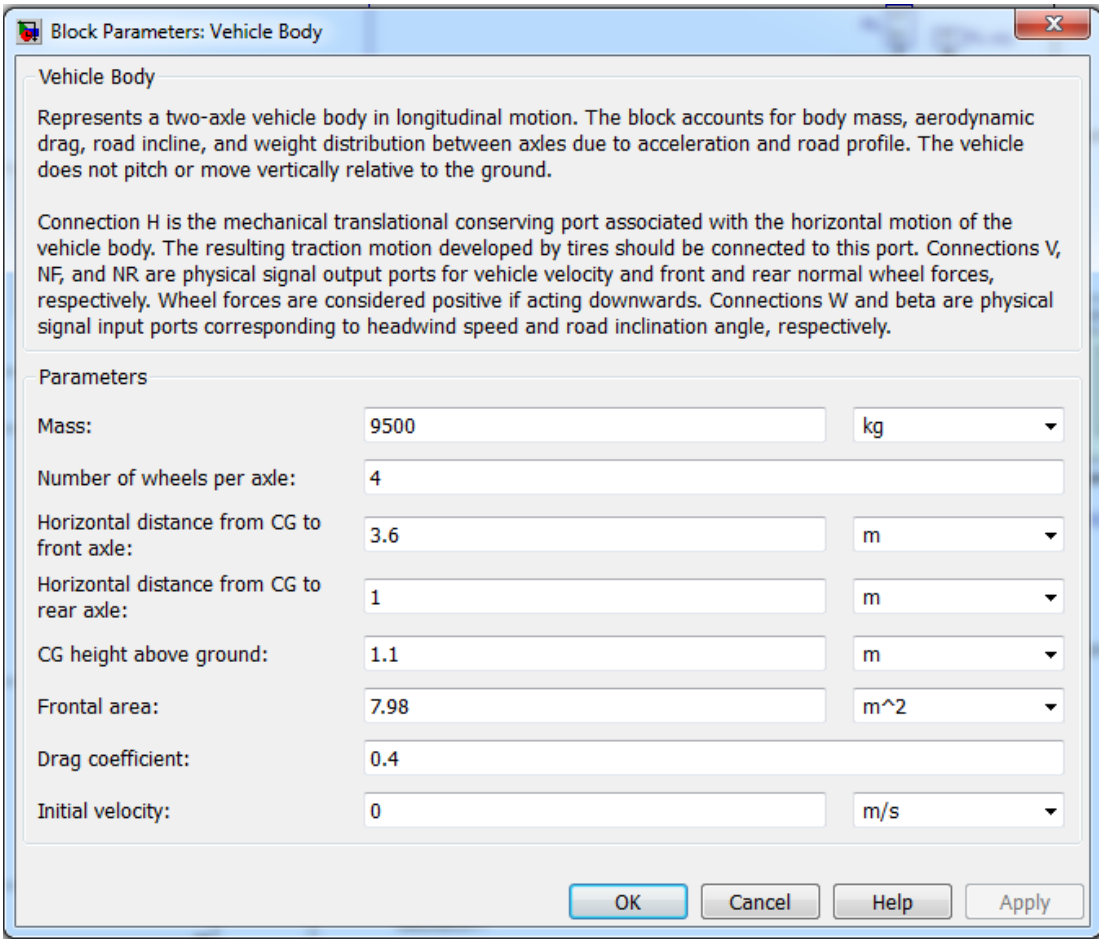


Figure 5.4. Vehicle Body Parameters

It was chosen mass 9500 kg, number of wheels per axle 4, horizontal distance from CG to front axle 3,6 m, horizontal distance from CG to rear axle 1 m, CG height above ground 1,1 m, front area 7,98 m^2, drag coefficient 0,4 and initial velocity 0 m/s as parameters of vehicle body.

5.1.3. Gearbox

The simple gear block represents a gearbox that constrains the two connected driveline axes, base (B) and follower (F), to corotate with a fixed ratio that you specify. You can choose whether the follower axis rotates in the same or opposite direction as the base axis. If they rotate in the same direction, w_F and w_B have the same sign. If they rotate in opposite directions, w_F and w_B have opposite signs. B

and F are rotational conserving ports representing, respectively, the base and follower gear wheels. Geaarbox model is shown below in Figure 5.5.

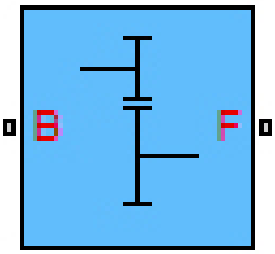


Figure 5.5. Gearbox Model

Fixed ratio g_{FB} of the follower axis to the base axis. The gear ratio must be strictly positive. NF/NB was chosen 2.32.

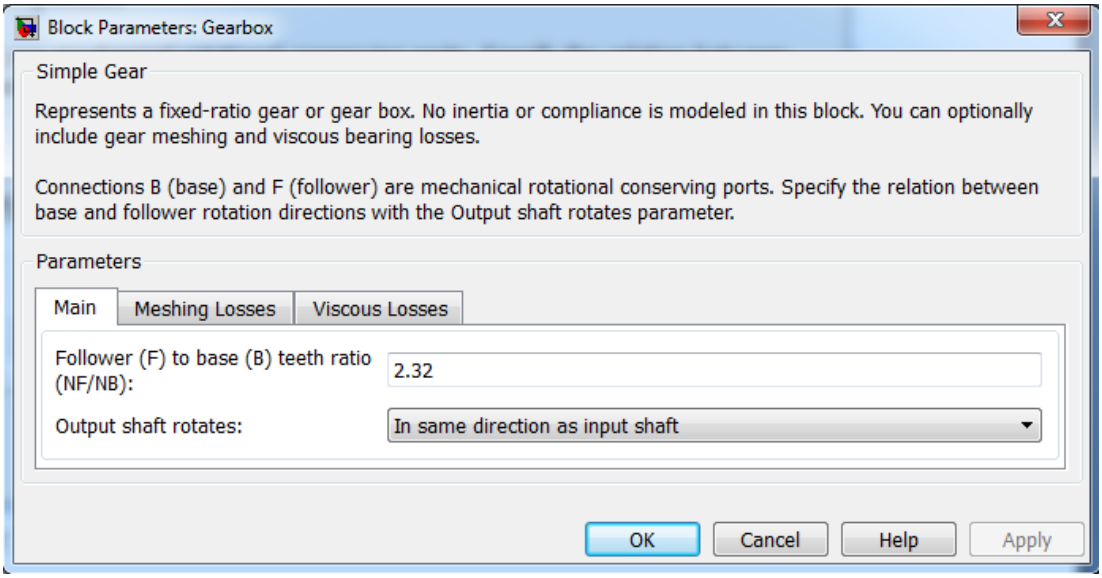


Figure 5.6. Gearbox Model Parameters

5.1.4. Torque Converter

Hydrodynamic torque converter transferring torque between two driveshafts. A torque converter couples two driveline axes, transferring torque and angular motion by the hydrodynamic action of a viscous fluid. The torque converter block

acts between the two ports I and T. Torque converter block is shown below in Figure 5.7.

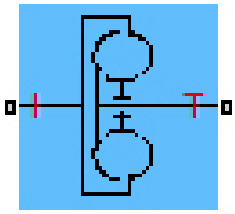


Figure 5.7. Torque Converter Block

Vector of values of the block function's first dependent variable, the dimensionless torque ratio Rτ. Each torque ratio value corresponds to a speed ratio value.

5.1.5. Differential

The differential block represents a differential gear that couples rotational motion about the longitudinal driveshaft axis to rotational motion about two lateral or side axes. Any axis can be the input. In normal use, the longitudinal driveshaft is the input, and motion, torque, and power flow out through the side shafts. Differential block is shown below in Figure 5.8.

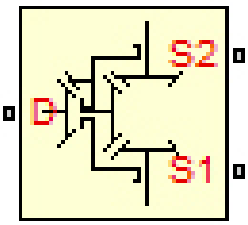


Figure 5.8. Differential Block

D, S1, and S2 are rotational conserving ports representing, respectively, the longitudinal driveshaft and the two side shafts.

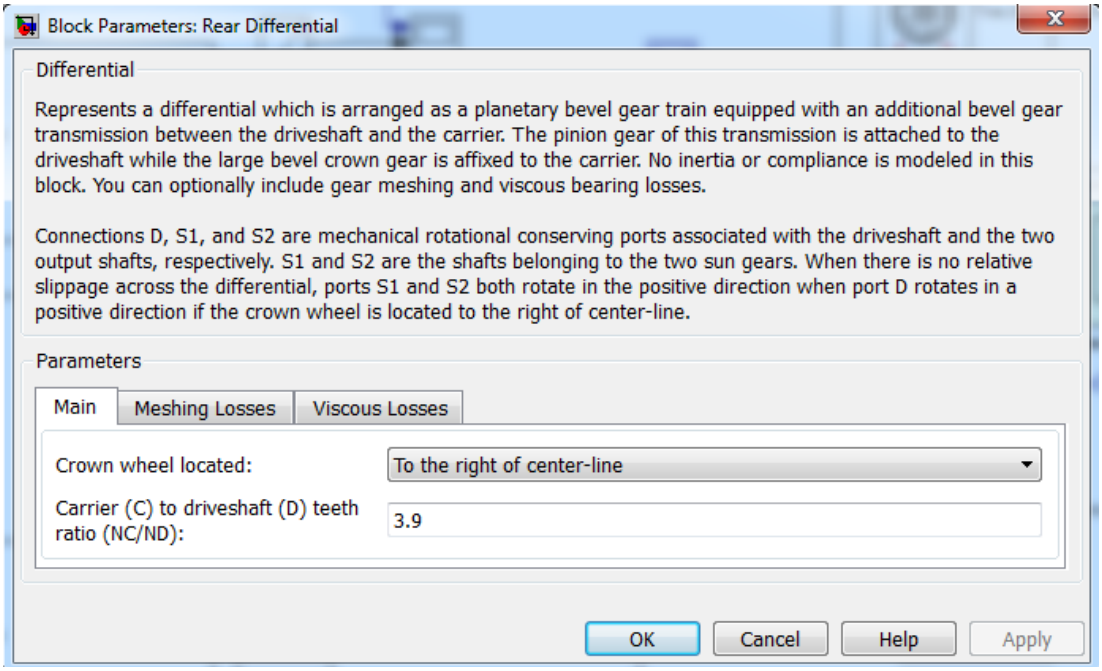


Figure 5.9. Differential Block Parameters

5.1.6. Tire

The tire block models the longitudinal dynamics of a vehicle axle-wheel-tire combination. The downward vertical load is specified as F_z through a physical input signal at port N. The block reports the developed tire slip κ, as a decimal fraction, through a physical signal output at port S. The wheel axle rotation is represented by the rotational conserving port A. The wheel axle transfer of horizontal thrust reaction to the vehicle is represented by the translational conserving port H. The longitudinal direction lies along the forward-backward axis of the tire. Tire block is shown below in Figure 5.10.

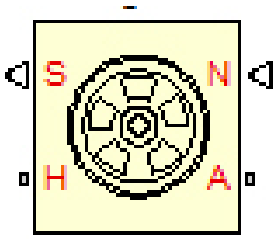


Figure 5.10. Tire Block

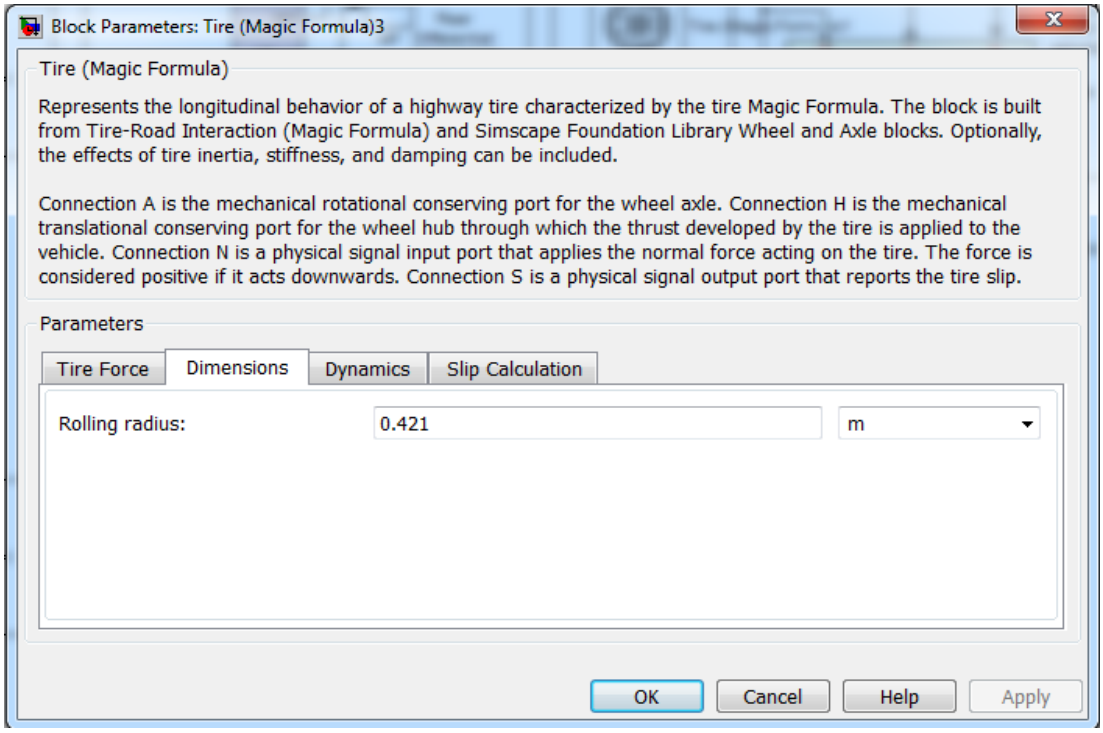


Figure 5.11. Tire Block Parameters

5.2. Simulation on the Matlab Simulink

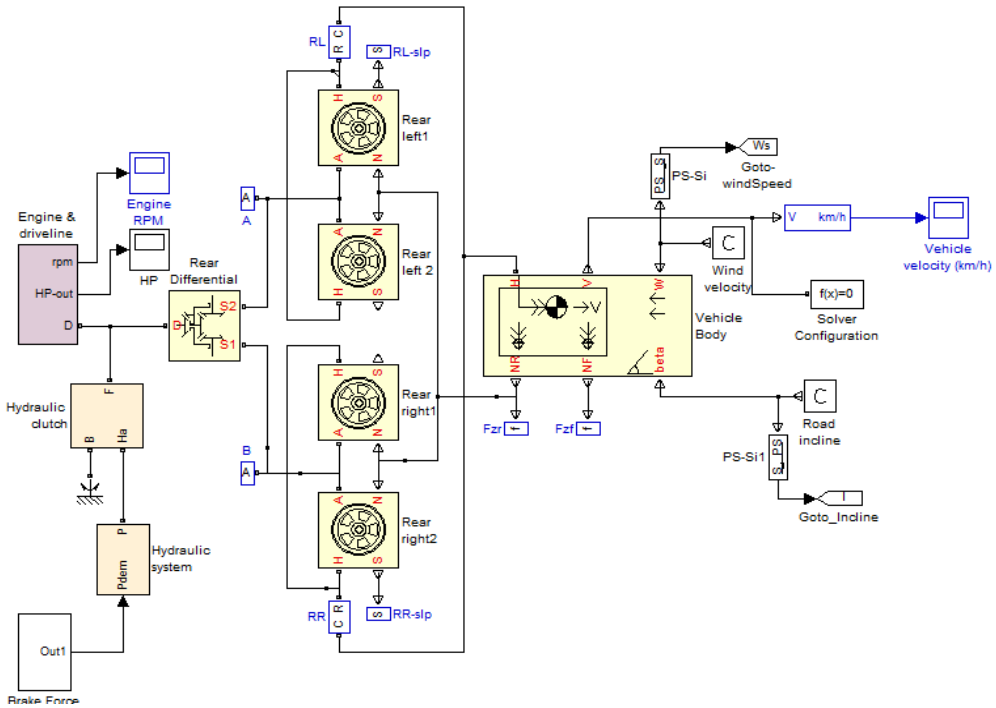


Figure 5.12. Simulation on the Matlab Simulink

5.2.1. Chosen Wind Velocity and Road Incline

To get closer to a real vehicle ambient, the slope and wind speed is given to simulation. We ignore air resistance so wind speed is equal to 0 m/s. Incline of road is equal to %5. That is, road rises 5 meters after 100 meters. Wind velocity and road incline are shown below in Figure 5.13.

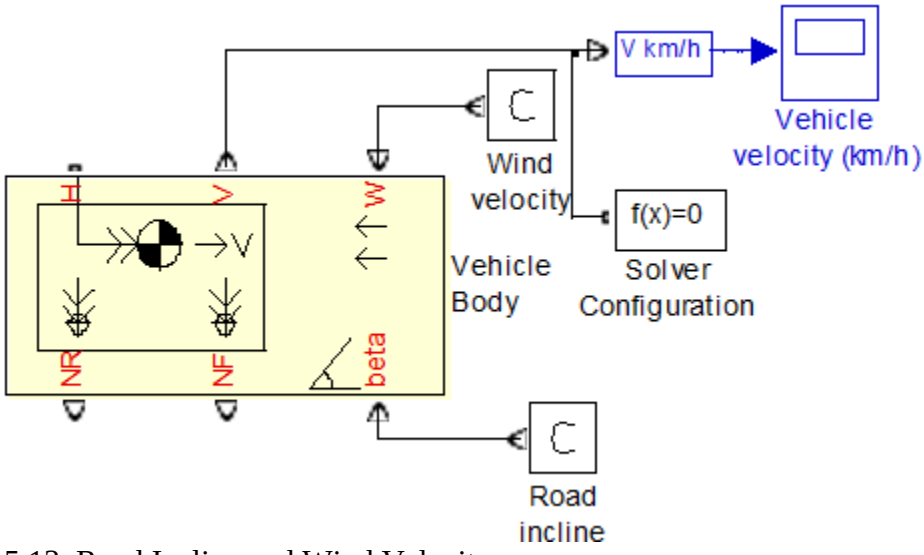


Figure 5.13. Road Incline and Wind Velocity

If it is desired, wind velocity and road incline are changeable.

5.2.2. A Viewing Relationship Between Body and Tire-Differential

S port on tire block indicates slip of tire. A port where longitudional force coming from the engine is applied and N port on tire block weight of vehicle body is entered. H port is computed angular velocity of rotating wheel. This block diagram is shown below in Figure 5.14.

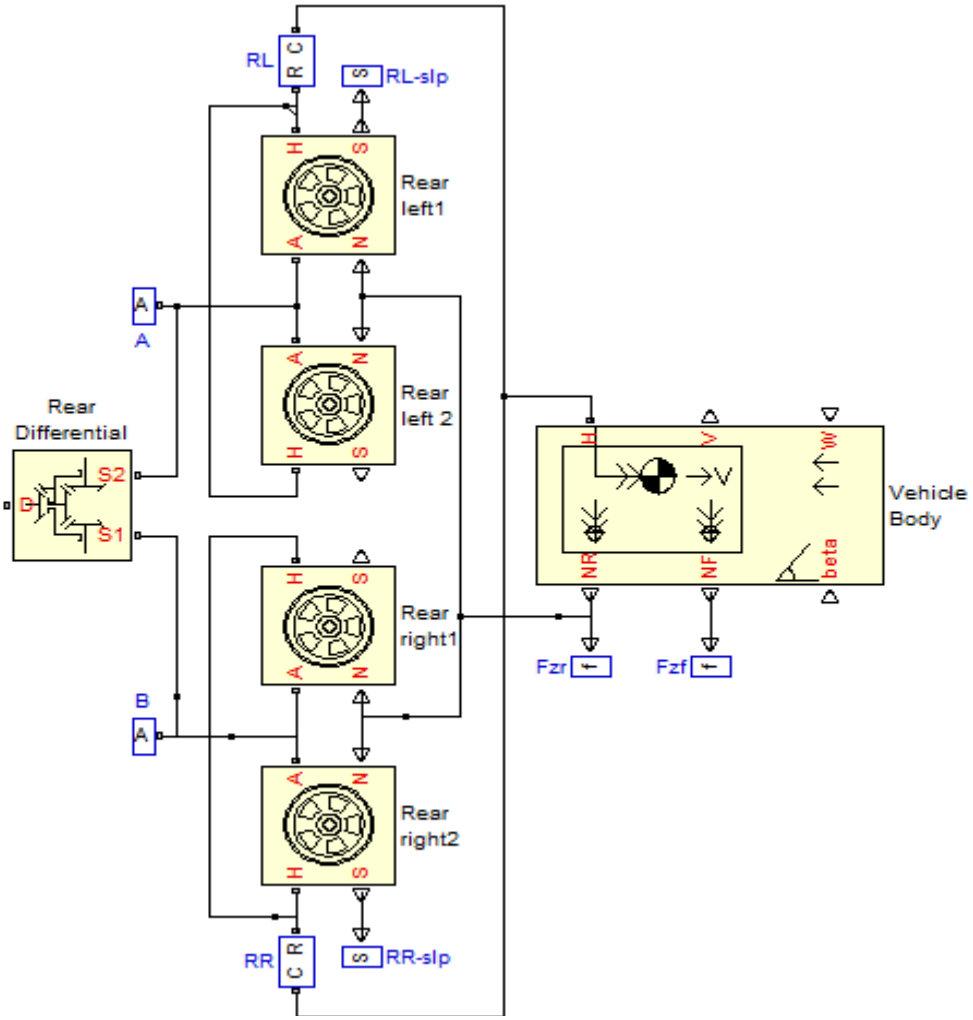


Figure 5.14. Relationship Between Body and Tire-Differential

The headwind speed is specified as W (in meters/second) and the road inclination angle is specified as β (in radians) through physical signal inputs at ports W and beta, respectively. The block reports the longitudinal vehicle velocity V_x and the front and rear normal forces (load on wheels) F_{zf}, F_{zr} as physical signal outputs at ports V, NF, and NR, respectively. The horizontal motion of the vehicle is represented by the translational conserving port H. Differential power transferred to the wheels from point A and B is shown in Figure 5.14.

5.2.3. Power Generating Components of Vehicle

Gas pedal is indicated as throttle signal, thus from the moment pressing the gas, the vehicle starts to work. Throttle signal must be between 0 and 1 (1 is shown as maximum gas). During engine running, power is transferred to tires via F port and value of power from P port is taken as kW and measured torque is taken from F port. It is shown below in Figure 5.15.

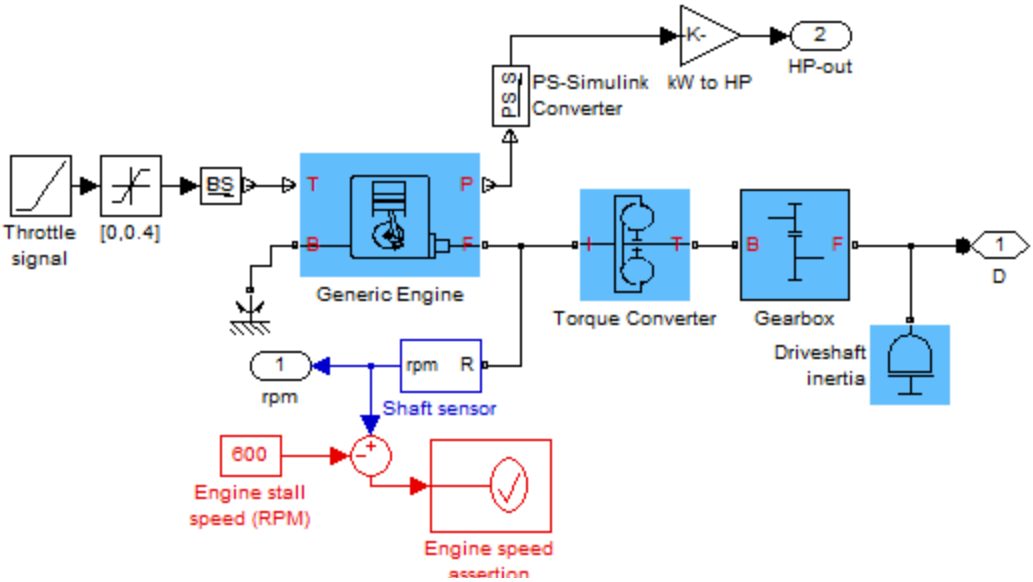


Figure 5.15. Power Generating Components of Vehicle

5.2.4. Braking with Hydraulic Clutch

During a hill start, the developed software provides safe and comfortable start without rolling backwards by activating service brakes with right conditions and timing. Current gear message and throttle pedal percentage are checked to deactivate vehicle braking. While vehicle braking is active, if the vehicle is in gear (included reverse gear) and throttle pedal percentage is greater than %10, vehicle braking starts to decrease and when throttle pedal percentage becomes %33, vehicle braking becomes zero. Vehicle braking is activated by hydraulic clutch in simulation.

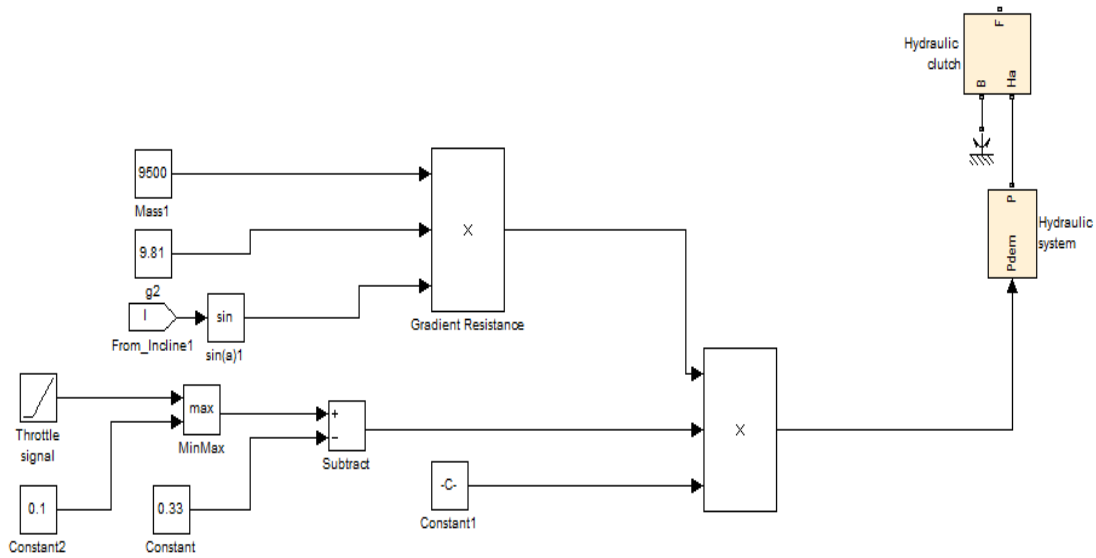


Figure 5.16. Hydraulic Clutch

5.3. Simulation Results

In this case, vehicle weight is 9500 kg. and road slope is %5.

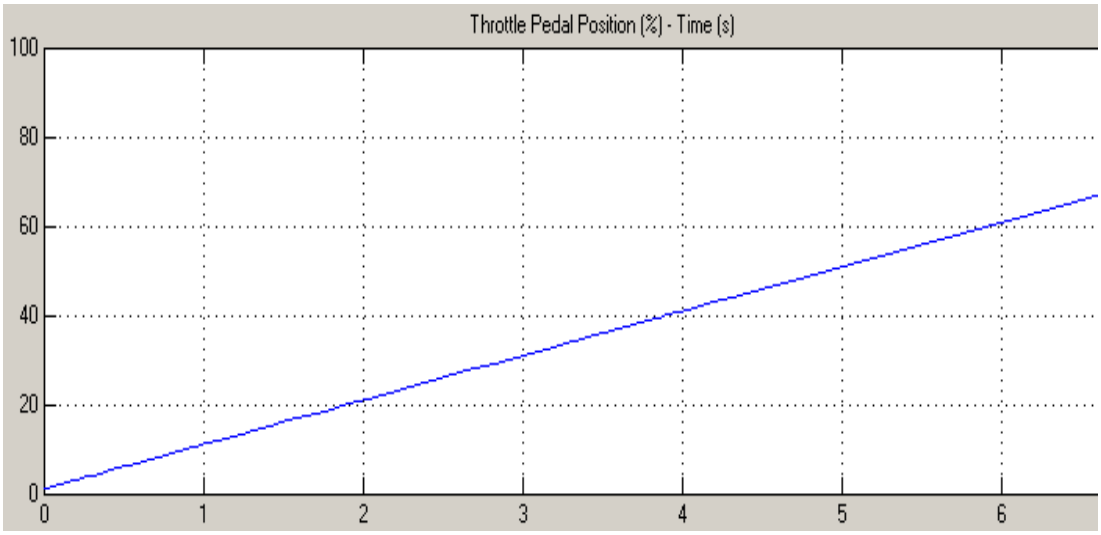


Figure 5.17. Throttle Pedal Percentage

Throttle pedal percentage is shown in Figure 5.17. Initially, its value is zero.

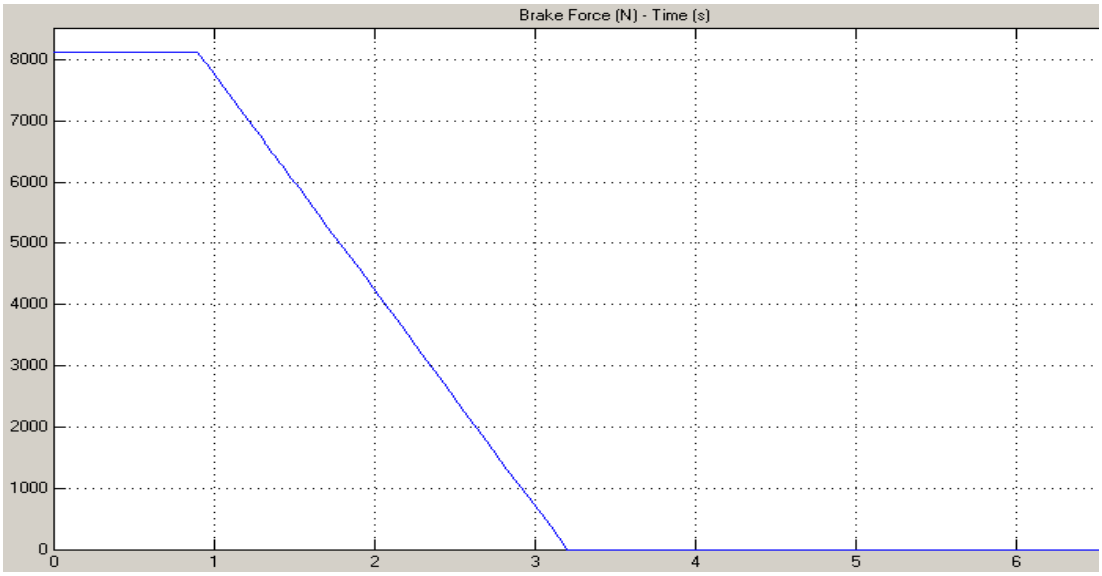


Figure 5.18. Brake Force

Brake force is shown in Figure 5.18. Initially, its value is 8122 N. When throttle pedal percentage becomes %10, applied brake force starts to decrease and when throttle pedal percentage becomes %33, applied brake force becomes zero.

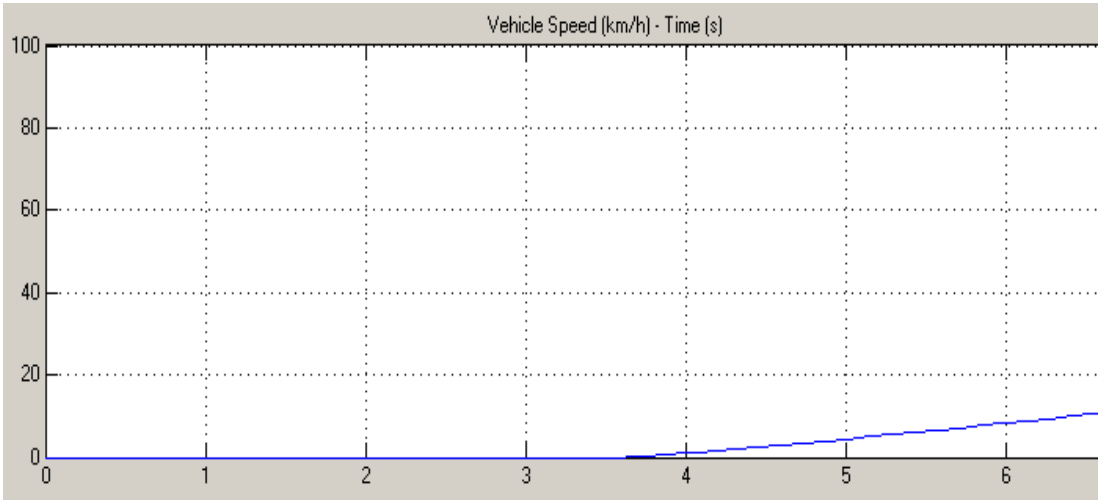


Figure 5.19. Vehicle Speed

Vehicle speed is shown in Figure 5.19. Initially, its value is zero. After applied brake force becomes zero, vehicle speed starts to increase.

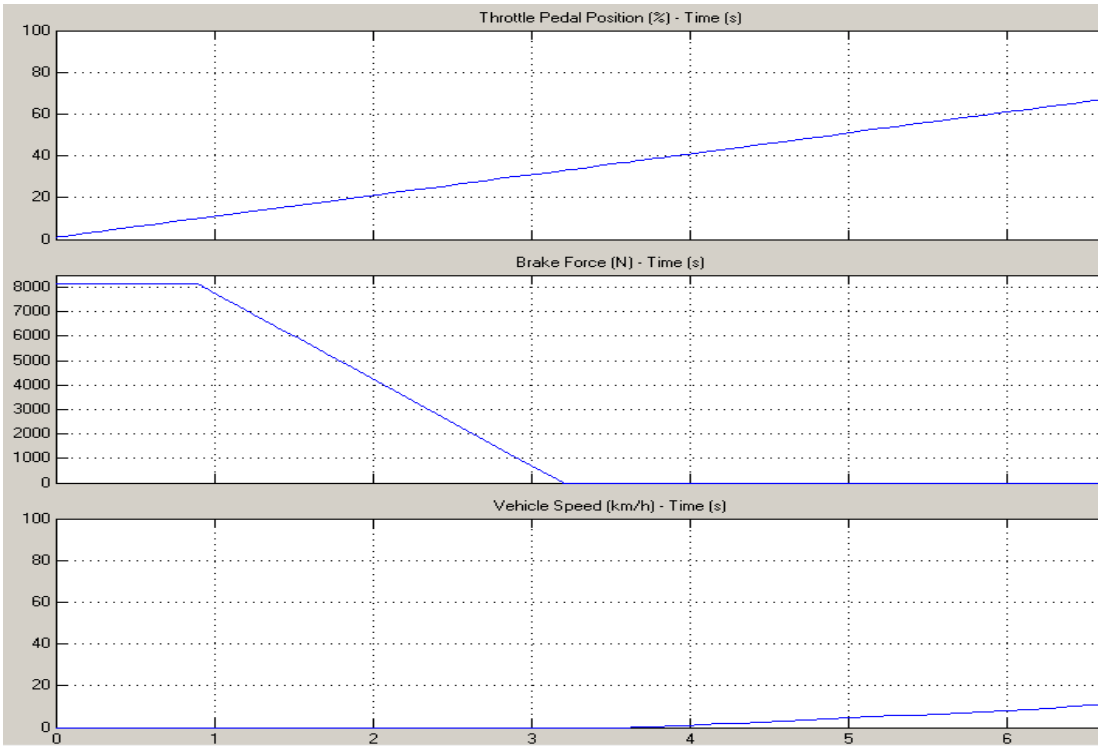


Figure 5.20. Simulation Result

Simulation result is shown in Figure 5.20. Vehicle weight is 9500 kg. and road slope is %5. Initially, brake force is 8122 N, throttle pedal percentage and vehicle speed are zero. When throttle pedal percentage becomes %10, applied brake force starts to decrease. When throttle pedal percentage becomes %33, applied brake force becomes zero. After applied brake force becomes zero, vehicle speed starts to increase.

5.4. Implementation Results

Tilt sensor, pressure sensors and gateway unit were installed to the vehicle. Then, necessary softwares were downloaded to the vehicle. Following data and graphics were taken with CANalyzer. CANalyzer is used to make the analysis of CAN(Controller Area Network) in automotive sector.

In this case, vehicle weight is 9500 kg. and road slope is %5.

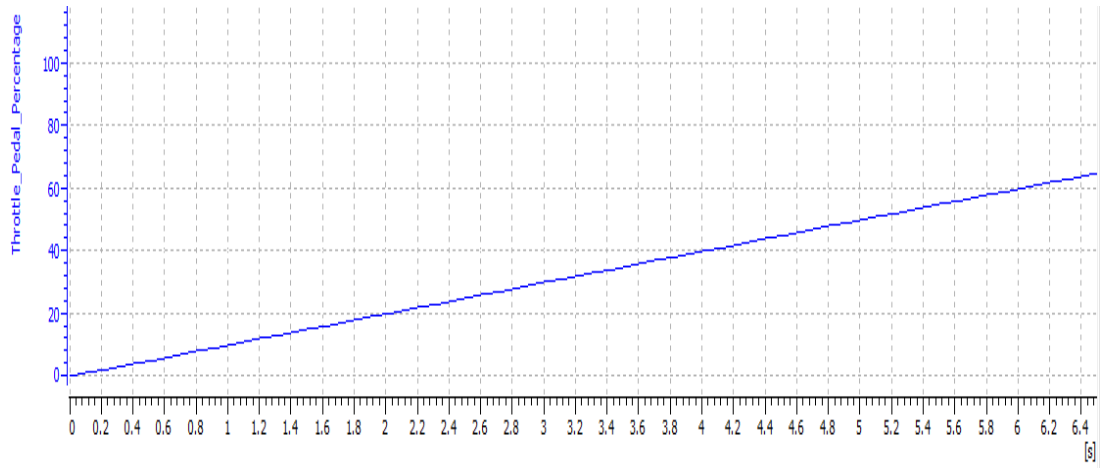


Figure 5.21. Throttle Pedal Percentage

Throttle pedal percentage is shown in Figure 5.21. Initially, its value is zero.

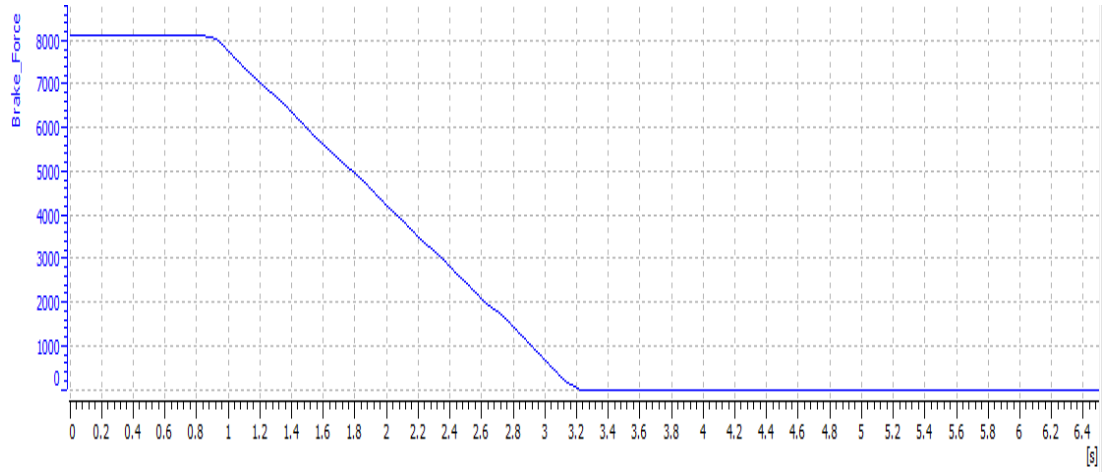


Figure 5.22. Brake Force

Brake force is shown in Figure 5.22. Initially, its value is 8122 N. When throttle pedal percentage becomes %10, applied brake force starts to decrease and when throttle pedal percentage becomes %33, applied brake force becomes zero.

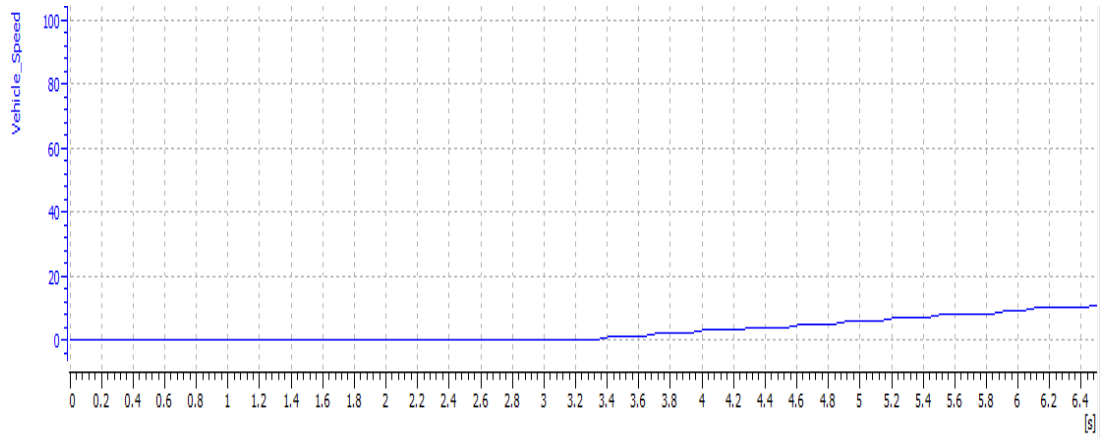


Figure 5.23. Vehicle Speed

Vehicle speed is shown in Figure 5.23. Initially, its value is zero. After applied brake force becomes zero, vehicle speed starts to increase.

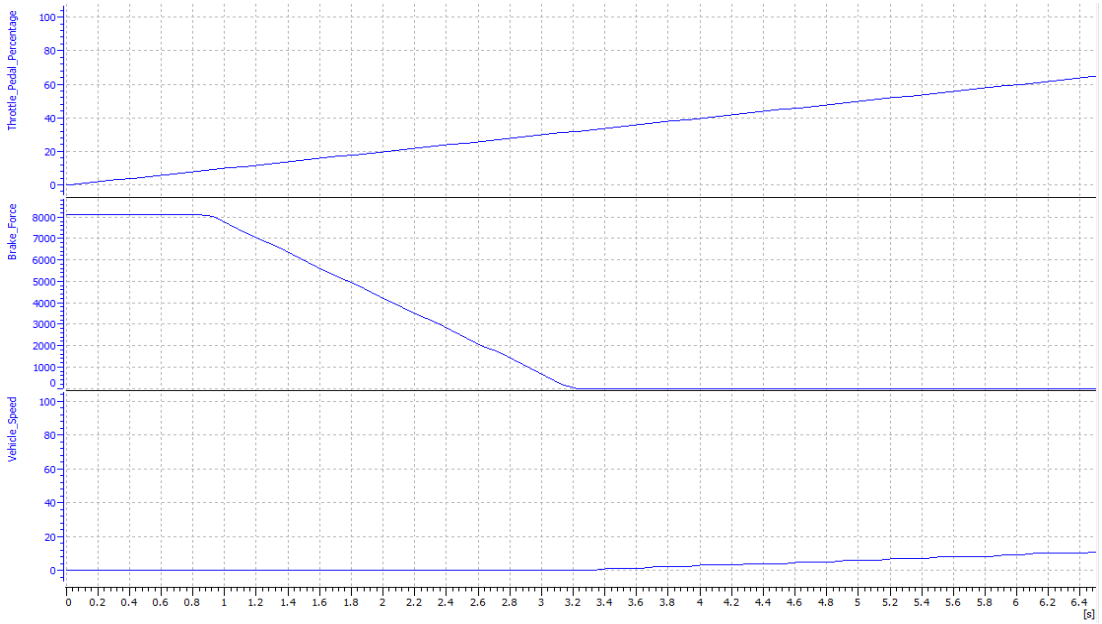


Figure 5.24. Implementation Result

Implementation result is shown in Figure 5.24. Vehicle weight is 9500 kg. and road slope is %5. Initially, brake force is 8122 N, throttle pedal percentage and vehicle speed are zero. When throttle pedal percentage becomes %10, applied brake force starts to decrease. When throttle pedal percentage becomes %33, applied brake force becomes zero. After applied brake force becomes zero, vehicle speed starts to increase.

6. CONCLUSION

In this thesis, studies related with hill start assist (hill holder), automatic park brake and halt brake were researched and the question: “how should a software for intelligent safety package which can work parallel to main brake system be developed” was answered. At the end of this thesis, an intelligent safety package software was designed and developed which consists of hill start assist function (hill holder), automatic park brake function and halt brake function.

The system is capable to collect data from the vehicle CAN (Controller Area Network), MUX (Multiplexer), tilt and pressure sensors. ZR-32 (Body Controller) activates or deactivates appropriate brake force when needed by the intelligent safety package software. The necessary software for the intelligent safety package algorithm is designed by LogiCAD. Information and warning messages related with vehicle system and intelligent safety package are displayed on an LCD screen which is placed on the instrument panel. The necessary software for the instrument panel is designed by Cavtan.

With this thesis, hardware and software for data collection from the vehicle CAN, MUX, tilt and pressure sensors that have been used on vehicle were recorded by using CANalyzer software on PC. The software was obtained by overcoming some issues and difficulties encountered during improvement studies, but solutions to these problems were found. It has seemed that software and hardware can be applicable to all commercial vehicles which use most common OEM products.

To be able to use this sytem on all commercial vehicles, a tilt sensor which is a sensitive and fast measurement tool is used to calculate tilt data which is one of necessary parameters for safety package software to determine if the vehicle is on the hill or not. The data from pressure sensors that are placed to vehicle blowers are calculated and by using this calculated data, weight of the vehicle is determined for one of another necessary parameters for safety package software. Data from these sensors are gathered on Multiplexer (MUX) module and transferred to vehicle control unit ZR-32. The same method is applied for parameters that are needed for developed safety package software such as park brake switch, vehicle speed,

passenger door switch etc. The vehicle on which necessary sensors were mounted and developed softwares were installed had been tested succesfully.

In the next step of this thesis, a new electronic control unit can be developed for intelligent safety package software to eliminate the dependence of a sole brake manufacturer. Thus, new developed intelligent safety package software can be used independently of any brake ECU. Consequently, there can be no doubt that this system can be sold to all vehicle manufacturer companies as a new product.

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