CHALMERS

Developing Enthusiast Features for Driveline Control in a Volvo car

Master's Thesis in the Automotive engineering program

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Cover:
Picture of the test vehicle during launch control tests on low friction surface.

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ABSTRACT

When the new Volvo S/V60 was released it was marketed as a sporty and dynamic car. The chassis and handling of the car makes it enjoyable and it communicates in a direct fashion with the driver which is greatly appreciated by journalists and enthusiast car drivers. The great reception of the car encouraged to investigate what that could be done within driveline control in order to make it even more fun to drive. In this thesis the following enthusiast features are developed and tested: Launch control, down shift support, controlled exhaust detonations during shifts, injection cuts for sound and response reasons, distinct/sporty accelerator pedal characteristics in neutral and a system for increasing the response of the engine after gear change. All features are implemented within the engine controller.

Models for the new functionality were developed in Matlab/Simulink. The launch control was simulated using VSim, a Volvo developed tool for longitudinal vehicle analyses. For the functionalities not well represented by VSim, measurement data from the test vehicle was run through the models to verify that the output signals were correct. The Simulink models were then adapted to the ECM and implemented into a test vehicle.

The test vehicle used was a Volvo S80 with a 2.5 liter turbocharged port fuel injected five cylinder engine, manual transmission and a Denso ECM. The testing and calibration was conducted on test tracks, regular roads and in a chassis dynamometer.

The result of the addition of new features is a car that is more fun to drive, offers quicker acceleration, better response and gives a more direct and sporty impression. Use of launch control gives quick and repetitive 0-100km/h times. The time to regain boost after gear change is reduced by 0.3 seconds and boost pressure never drops below 160kPa absolute pressure with the response system active. The "Skip stroke" injection cut strategy proved to be useful for building torque reserves with very moderate exhaust temperatures. The down shift support gives a smoother and more stable ride while letting the driver impress his friends with his down shifting skills. The sportier accelerator pedal characteristics proved to make the communication between car and driver feel more direct and finally the addition of exhaust detonations during gear changes makes it impossible not to smile.

Key words: Passenger car, enthusiast features, launch control, driver perception, engine controller, response system.

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Preface

In this report the development and testing of features aimed towards car enthusiasts is presented and documented. It describes the process from idea to final results and also includes recommendations for improvements and future work. The work has been carried out in the time period from January to June of 2011 at the department for Engine Controls and Calibration under the Powertrain division of Volvo Car Corporation in Torslanda, Sweden. The project was initiated and financed by VCC.

The project has been supervised by Gasoline Engine Control Specialist Fredrik Wemmert of VCC and the examiner was Professor Bengt Jacobson from the Vehicle Dynamics group, Division of Automotive Engineering at the Department of Applied Mechanics, Chalmers University of Technology, Gothenburg, Sweden.

Thanks goes out to all VCC employees that have helped, supported and urged us on along the way. Special thanks to Fredrik Wemmert, Anders Brandt, Anders Johnsson, Stefan Krümmel, Daniel Lundberg and Olof Daunius for their involvement and enthusiasm throughout the project. Thanks also to Denso Sweden for their help and support.

Torslanda June 2011

Henrik Hellström and Anders Vikström

List of abbreviations

BCM	Brake Control Module
BDC	Bottom Dead Center
BTDC	Before Top Dead Center
CAD	Crank Angle Degrees
CAN	Controller-Area Network
CEM	Central Electronic Module
CVC	Complete Vehicle Control
ECM	Engine Control Module
EMS	Engine Management System
ESC	Electronic Stability Control
ETK	Emulator-TastKopf (Emulator probe)
MBT	Maximum Brake Torque
PID controller	Proportional–Integral–Derivative controller
SI	Spark Ignited
TCM	Transmission Control Module
TDC	Top Dead Center
VCC	Volvo Car Corporation

1 Introduction

1.1 Background

When the new Volvo S/V60 was released it was marketed as a sporty and dynamic car. The chassis and handling engineers had put a lot of effort into making the car communicate with the driver in an enjoyable and direct fashion that was greatly appreciated by journalists and enthusiast car drivers. The reception of the vehicle showed that a large portion of the journalists and customers really were demanding and waiting for a sporty Volvo. This encouraged the idea to initiate a prestudy, within the department for Driveline Control, with the goal to find and demonstrate enthusiast features specifically aimed towards driveline control.

1.2 Purpose

The purpose of the master thesis is to find and develop features within the driveline controller and implement these in a test vehicle. These might be features that result in an objective and/or a subjective improvement on the vehicle performance. That is, it could be something that actually makes the car perform better but it could also be something that improves how the vehicle is perceived by the driver. The purpose is also to get an understanding of the requirements of these features and what they require from the engine controller and the surrounding systems.

1.3 Goal

The goal of the project is to come up with a large number of possible enthusiast features, giving VCC a palette to choose from in future projects. Some of them will be selected and realized within this thesis work by implementing them in a demo vehicle. The addition of these features should contribute to the driving experience in a positive manner. The features will also be analyzed and compared to the original vehicle in terms of gain in perceived and actual performance. Both manual and automatic transmission vehicles should be considered. Requirements and limitations in the driveline and its control as well as in surrounding systems shall be briefly analyzed and documented. If these features are to be implemented for production it is important that they do not influence the overall emissions and fuel consumption, this will be of minor concern in this thesis.

1.4 Method

The method used for this project is to first brainstorm and come up with enthusiast features that can add customer value to the product. The features are analyzed in order to see if they are possible to implement with today's software and hardware components.

To develop and implement features in the Engine Control Module (ECM) programs available at Volvo is used. The features are modeled using Matlab/Simulink together with a toolbox from the ECM supplier. To evaluate straight line vehicle behavior a Volvo developed Matlab tool, VSim, is used. In VSim features can be implemented and the actual performance gain can be estimated. In order to test other functions vehicle measurements is made and the collected data is implemented in Matlab.

The functions developed during the simulation process are remodeled in order to adapt them to the Engine Control Module (ECM) software structure. In the case the modifications are within the Volvo Car Corporation (VCC) developed software part, code is generated and implemented at VCC, this is done with TargetLink. In the case the modifications are within the ECM supplier software, specifications are defined and the supplier will implement them into the software. When the functions are adapted and implemented in the ECM, vehicle tests is conducted. The functions are calibrated to achieve the desired enhancements and the results are evaluated. ETAS engine calibration tool INCA is used to calibrate the functions in vehicle.

A Volvo S80 2.5T, 5 cylinder turbo charged engine, is used to evaluate the features that are applicable to vehicles with manual transmission. Tests are performed both on the road and in a chassis dynamometer. To present the control functions and their effect on performance both the actual enhancement and the perceived enhancement are demonstrated in a vehicle.

1.5 Limitations

The implementation of the features and functions developed and described within this project are limited mainly to alterations within the engine controller software. Minor hardware modifications and changes in software elsewhere than in the engine controller are possible if considered absolutely necessary.

The vehicles that the new functionalities are tested on and designed for have port fuel injected spark ignited five or six cylinder turbocharged engines. Diesel engines are not considered within the scope of the project.

During the brainstorming part of the project the focus is solely on finding enthusiast features. The effects the addition of such features may have on functions and vehicle attributes are not considered in this stage. The limitations also extend to what is possible to develop in the engine controller within the timeframe and resources of the thesis work.

An industrialization plan or a plan to make the new functions comply with current legislations is not within the scope of the project.

2 Background theory

This chapter gives a basic description of theory relevant to the project

2.1 Vehicle and tire dynamics

During straight line acceleration the longitudinal dynamics of the vehicle are important to evaluate. A fictive force (inertia force), F_x, is generated in opposite direction to the vehicle motion and acts from the vehicle center of gravity, seen in Figure 1.

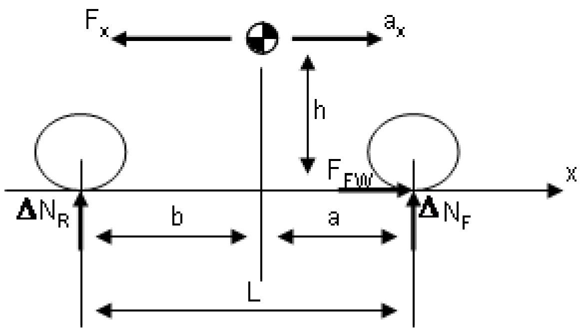

Figure 1 Longitudinal weight transfer

This force generates a pitch moment on the vehicle which results in a longitudinal weight transfer causing the normal load on the tires to change, according to Milliken [1]. During straight line acceleration the normal load on the front tires will decrease. The resulting change in load on the front tire is seen in equation (3) which is derived from equation (2). Since the vehicle used in this project has front wheel drive, the longitudinal force the front wheels can produce will decrease due to the decrease in normal load under acceleration. In equation (4) the dependence between the maximum achievable tire force F_{FW}, normal load N_F and the surface friction μ_F is seen.

$$F_x = m_{tot} a_x \tag{1}$$

$$\Delta N_F L + F_x h = 0 \tag{2}$$

$$\Delta N_F = \frac{-F_x h}{L} = \frac{-m_{tot} a_x h}{L} \tag{3}$$

$$F_{FW} = N_F \mu_F \tag{4}$$

When talking about tire slip a simple explanation is that the tire slip is the difference between the tire rotational velocity compared to the tire translational velocity relative to the ground, i.e. the vehicle speed. A way to calculate the front wheel tire slip is to compare the (driven) front wheel speed, ω_F, with the (undriven) rear wheel speed ω_R, assumed as the vehicle speed. See equation (5).

$$S = \frac{\omega_F}{\omega_R} - 1 \tag{5}$$

Tire slip complicates the estimation of the force that can be generated from the tire. Hans B. Pacejka [2] has developed a model, the magic tire formula, that is widely used and recognized, see equation (6).

$$y = D\sin[C\arctan\{BS - E(BS - \arctan BS)\}] \tag{6}$$

The coefficients B, C, D and E are stiffness factor, shape factor, peak value and curvature factor respectively. In Figure 2 examples of mu-slip curves for different surfaces are seen. It is clear that the peak value is more noticeable in dry conditions hence it is more important to maintain a certain slip when accelerating a vehicle as fast as possible.

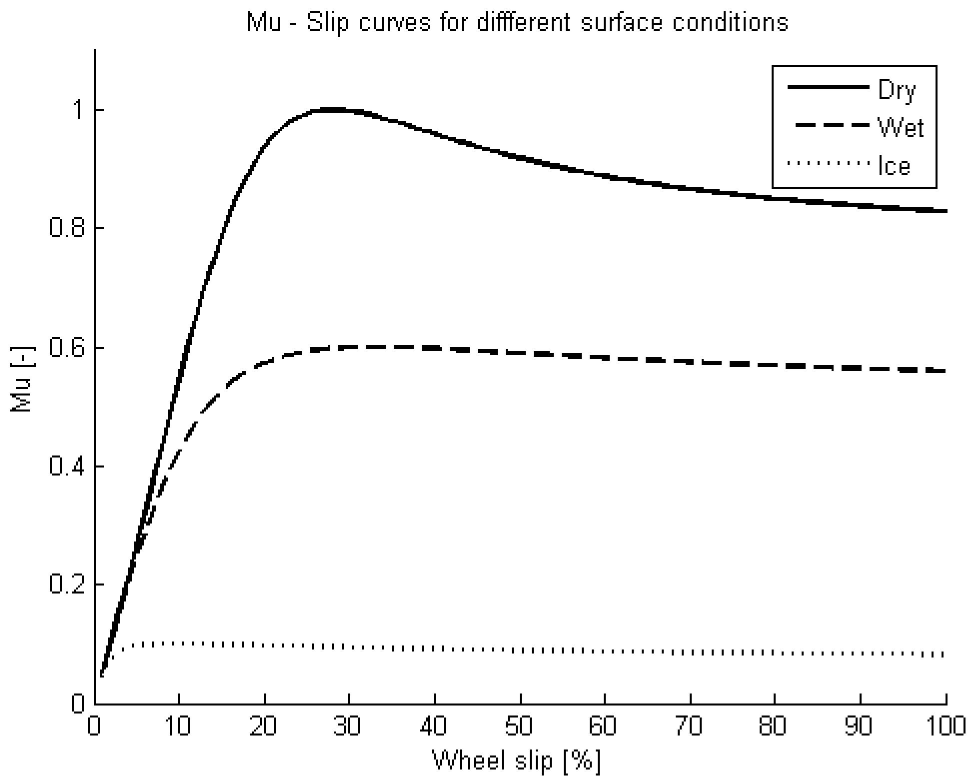

Figure 2 Mu - Slip graph for different surface conditions

2.2 Internal combustion engines

The engines discussed in this report are spark ignited (SI), port fuel injected, 4-stroke piston engines. In Figure 3 a schematic view of a turbo charged SI engine can be seen. The outline is the same as the five cylinder engine in the Volvo S80 that is used to demonstrate the features in this project. The four strokes are intake, compression, expansion and exhaust stroke. The intake stroke starts when the piston is at its top position, top dead center (TDC), and ends at its bottom position, bottom dead center

(BDC). During this stroke air/fuel mixture enters the cylinder. When the intake stroke ends the compression stroke starts and the mixture is compressed and ignited close to TDC. During the expansion stroke the mixture is burned, forcing the piston down, and then pushed out from the cylinder during the exhaust stroke. One stroke is 180 crank angle degrees (CAD) which concludes that a full four stroke cycle is 720 CAD.

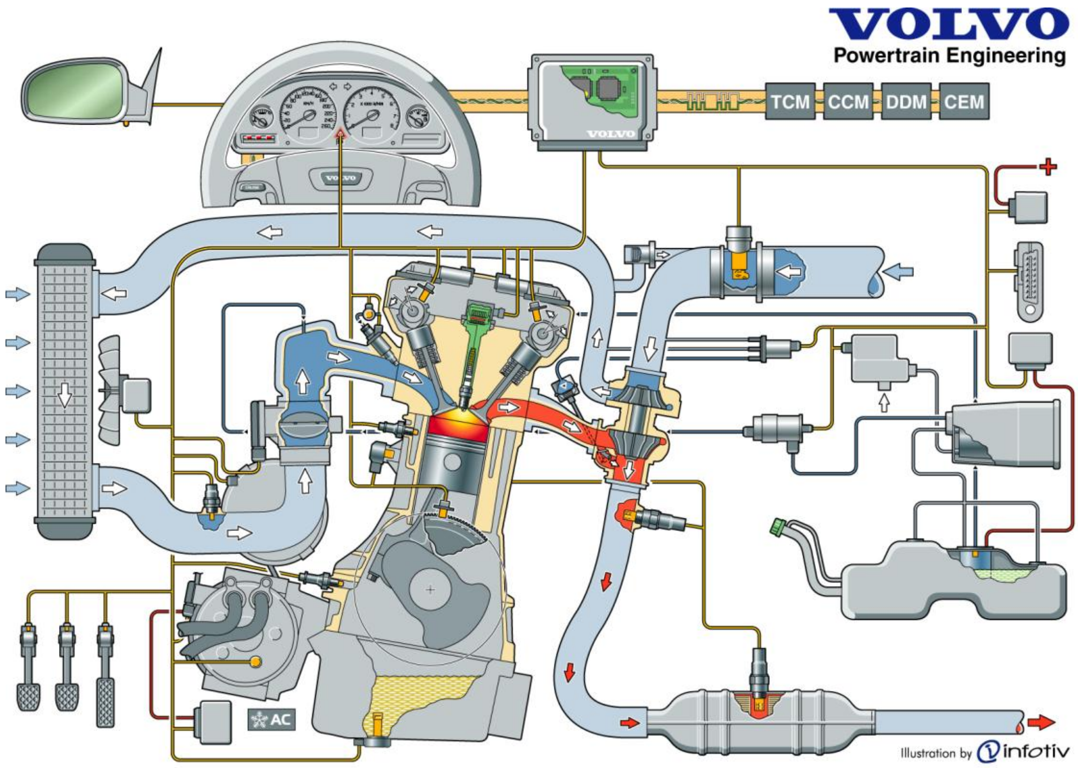

Figure 3 Schematic view of a SI four stroke engine, Infotiv [6]

In SI engines with port fuel injection the air charge and fuel mixes in the intake port before entering the combustion chamber. The mixture enters the engine during the intake stroke via the intake valve. When the piston moves downwards a low pressure region is created in the combustion chamber which causes the air to flow from the intake manifold in to the combustion chamber. During the compression stroke the mixture is ignited a certain angle before TDC (BTDC). This is followed by the expansion, or power stroke, and then the exhaust stroke.

The intake valve opens close to TDC before the intake stroke starts and it closes near BDC after the intake stroke is finished. The valves are closed during compression and expansion. Close to BDC late during the expansion stroke the exhaust valve opens and it closes slightly after TDC when the exhaust stroke is finished.

For engines that have a high speed range it is common to have a larger overlap between the intake and the exhaust valve opening times, they are open at the same time. The intake valve opens late in the exhaust stroke and the exhaust valve closes early in the intake stroke. At high engine speeds it is possible to utilize the pressure differences to increase the volumetric efficiency. If this setting is used at low engine speeds the engine will not be stable due to backflow of exhaust gas residuals into the combustion chamber. Late exhaust valve closing is good for power but with a loss in low speed torque, Heywood [3]. In most modern vehicles the valve timing is variable, either both intake and exhaust timings or only one of them. This makes it possible to utilize the high speed range performance but still keep the combustion stable at low speeds.

The mixture is ignited between 10 CAD after TDC to 40 CAD BTDC. This is also commonly where the point of maximum brake torque (MBT) is found. Retarding the ignition causes the exhaust gases to reach higher temperature since the combustion is delayed and takes place closer to the exhaust valve opening. The opposite if the timing is advanced.

The air-fuel ratio should be about 14.7:1 (air: fuel) when using gasoline for stoichiometric combustion, this is necessary for the catalytic converter to work properly. To achieve this, it is common to use a mass air-flow sensor mounted up stream of the manifold inlet and an oxygen sensor in the exhaust manifold. It is also possible to use a pressure sensor in the intake manifold. Using one or a combination of the sensors and knowing the engines volumetric efficiency the air mass trapped by each stroke can be estimated and thereby the required amount of fuel can be calculated.

The five cylinder engine used for demonstration is equipped with a turbocharger which is an air pump driven by the exhaust gas energy pressurizing the intake manifold. A turbocharger utilizes energy that on a naturally aspirated engine would have been wasted, increasing the engine efficiency.

2.3 Vehicle electronics

A vehicle is fitted with multiple control modules for different subsystems. The control modules communicate with each other via a CAN-bus. The heart of the system is the Central Electronic Module (CEM). This contains a car configuration that specifies what kind of car it is, what components are present etc. This information is sent out on the CAN-bus for other modules. An illustration of the CAN-bus and the electronic modules can be seen in Figure 4. Signals are sent out by modules to the CAN-bus without knowing who the recipient is. For example the Brake Control Module (BCM) measures the wheel speeds from all four wheels. The wheel speed information is also picked up by the ECM where the launch control functionality uses them to depict the correct torque request from the engine.

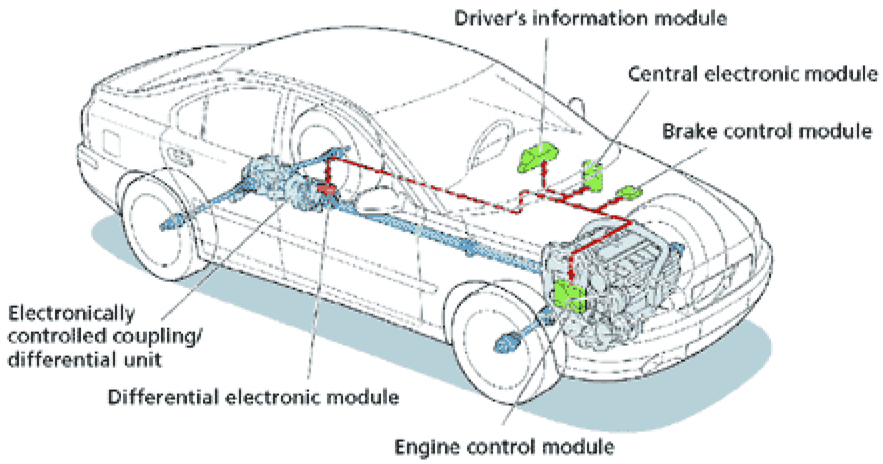

Figure 4 Possible electronic modules on the CAN-bus, Infotiv [6]

2.4 Engine management system

The engine management system lies within the ECM. The engine operation and control of modern cars is fully handled by computers, there is no mechanical interaction between the engine and the driver. The accelerator pedal is a potentiometer that creates a signal for the Engine Management System (EMS) to interpret. The advantage with this system is that the signal from the driver can be interpreted and converted to actions corresponding to what the driver wants in the most suitable way for a given situation. This signal is converted to a torque request from the driver. This passes through a series of filters and logic blocks before it is actualized. Along the way other systems or functions might have something to say about the request and want to alter it. For example it could be that the Electronic Stability Control (ESC) detects wheel spin and therefore reduces the torque. The program in the ECM consists of three main parts; the Volvo specific CVC (Complete Vehicle Control), the Denso application software and the platform software. Basically it can be said that the CVC part handles inputs from the driver and other on-board system such as ESP that might need to alter the torque request. The final torque request is then calculated and passed on to the Denso application software which realizes the request.

The torque request is divided in to two parts, one base request and one instantaneous request. The base request is actualized by air through the throttle valve and the instantaneous request is actualized through control of fuel injection and spark advance. The base request can be considered to be for slowly varying requests and the instantaneous for fast varying requests. Most of the time these two requests are identical but sometimes a system can request a quick change in torque and then the instantaneous request is used. A difference in the two request (Base>Instantaneous) is considered to be a request of torque reserve. Running the engine with a torque reserve means that the throttle valve is opened more than it normally would be to deliver a given crankshaft torque, the extra air is compensated for by retarding the spark angle so the same torque output is achieved, but with a lower combustion efficiency. The advantage of running the engine in this mode is that it is possible to increase the crankshaft torque up to the level of the base torque request in one combustion.

The Denso application software takes the torque requests and calculates the engine parameters such as air, fuel and spark needed to realize the request. All combustion and emission control is handled by this block. It also includes the idle speed controller, knock detection, over heating protection and more. The desired values for air, fuel, spark etc. are passed on to the platform software which translates it to an output signal suitable for the actuator in question (throttle valve, injectors, valve timing actuators etc).

3 Feature collection and selection

To find out what features engineers at VCC think can be a potential part of future Volvo cars, two brainstorm meetings were set up at Volvo. Also friends of the authors were consulted in order to get an opinion from non-Volvo employees. In this chapter a selection of features and areas were enhancement can be made are described. A selection is made from this list concerning which ones that will be taken to a stage of modeling and implementation. In Appendix A a complete list and short description of all the features from the brainstorming is shown.

3.1 Collecting and listing of features

In the list below a selection of the features from the brainstorm meetings is presented. The list represents a first selection and the main criterion is that they are possible to achieve within the scope of the master thesis. This list combined with the list in Appendix A represents all the features resulting from the brainstorm meetings.

1. **Response system during up-shift**

   A problem with turbocharged engines is that the turbocharger speed decreases during a gear change which creates a lag in the air charge system. The lag represents the time it takes for the turbo charger to reach the required speed to generate the correct pressure ratio at full load. This gets more obvious after a gear change during hard acceleration when utilizing the engines full capability.

   When making a gear change the accelerator pedal is released to reduce the torque, preventing the engine to over speed when the clutch pedal is pressed. During this maneuver the throttle valve closes reducing the gas flow and the fuel amount, the engine generates less energy to drive the turbo charger. The aim is to retain the turbo speed high during gear change while maintaining a low engine output torque.

2. **Launch control**

   If a vehicle has a powerful engine or if the traction is limited, it is hard for a driver to achieve repeatable quick starts from stand still both with manual or automatic transmission. In a vehicle with manual transmission it is necessary to control the throttle and clutch rate in the start and then control the wheel slip during acceleration. With an automatic transmission it is a little easier because there is no clutch to think about.

   To perform a maximum acceleration take-off with an automatic transmission it is needed to stall the gearbox. This is done by pressing the brake and the throttle pedal max at the same time. The engine will deliver a torque controlled by the ECM in order not to exceed limits compromising the driveline durability. It is also important to be aware of the torque amplification that exists when the automatic gearbox is stalled.

The aim is that the driver only should concentrate on steering the vehicle and shifting gears. For an automatic transmission the first stage is different and the second is similar.

The reason the regular spin and traction control system does not work in this situation is that it is optimized for not spinning the wheels and not stalling the engine. The intention with a launch control is to get the wheels spinning and then keep them spinning for as long as possible. It is also important to control the torque with the instantaneous torque request in order to not bog the engine, as is the case with the standard anti spin controller.

3. **Down shift support with manual transmission**

During heavy braking combined with downshifting maneuvers at high engine speeds there is a risk to get a decrease in lateral stability due to engine braking when releasing the clutch. If the clutch is released too fast the wheels can lock. This is most evident for race drivers in corner entry and they solve the problem with a "heel and toe" maneuver, braking with the toes and blipping the throttle pedal with the heel. To make it easier for more inspired driving it is possible to let the ECM match the engine speed with the gearbox speed.

4. **Controlled exhaust detonations**

A common belief among auto enthusiasts is that the sound of exhaust detonations during gear change or when letting go of the throttle at high engine speeds is something that is desired. This makes the car sound more aggressive, gives it more character and is often associated with race engines.

To get exhaust detonations a certain amount of unburned mixture needs to end up in the exhaust manifold and be ignited there. This sometimes occur uncontrolled due to misfires. The goal is to generate exhaust detonations in a controlled way.

5. **Skip stroke**

Skip stroke is a phenomenon where the cylinder starts to fire only on every fourth revolution, most likely due to the reciprocating characteristics causing excessive amounts of internal EGR, exhaust gases being pushed back into the cylinders at certain engine speeds where the exhaust system is "out of tune". The sound is sometimes appreciated since it gives the engine a special character. To achieve this synthetically either the ignition or the fuel needs to be cut every second time. To prevent an excessive amount of fuel in the exhaust system and there by damage to the catalyst it is better to control the fuel amount instead of the ignition.

6. **Idle running conditions**

The idle running conditions of a standard car engine is very stable and smooth compared to that of a highly tuned racing engine, which sputters and gives of a special sound signaling performance to the surrounding people. If the car can be set in a sport mode this could be used to alter the idle running to a more race like setting.

A raised idle speed can give a part of the wanted behavior. Another way to alter the idle behavior is if the engine has a variable valve train. Then it is possible to adjust it for more overlap which results in more residuals in the combustion hence a "rougher" idle, like a racecar. A flywheel with low inertia could also be an enabler for the desired uneven idle behavior.

7. **Better throttle response in neutral**

   When revving the engine in neutral gear or holding the accelerator pedal at a fixed position the pedal map demands a torque, as opposed to a speed, from the engine. The engine ends up at a speed corresponding to where the delivered torque is equal to the friction torque. Today it is hard to keep the engine at a fixed speed which results in a strange feel of the link between the accelerator pedal and the engine. Another aspect that ads to this feel of uncertainty is that more than 15% accelerator pedal position corresponds to maximum engine speed. The idea is to try and match different pedal positions with fixed engine speeds.

8. **Power increase with engine speed**

   In the vehicles today the maximum torque curve at wide-open throttle is almost flat which means that there is a feeling of constant acceleration which results in the engine being perceived as dull. If the torque is increasing from low engine speeds the driver will perceive that the vehicle acceleration increases with engine speed.

3.2 Feature selection

In consolation with development engineers at Volvo, investigation of the feature definitions in section 3.1 and from the list in Appendix A, a number of features are selected. As stated in the beginning of this chapter the first selection is made with the main criterion that they are possible to achieve within the scope of the master thesis. When looking at the features it is obvious that some are more time consuming than others. For example the launch control which involves more parameters will take a longer time to develop than the throttle response in neutral, which only needs a recalibration to be tested. This makes it possible to combine features that are more time consuming with features that possibly only require recalibration of the existing software.

Features number one to five and number seven from the list in section 3.1 are selected to be developed and realized. They were selected due to high popularity and will result in a package of features suitable for demonstration.

4 Feature development and simulation

This chapter is divided in to the development process of each feature, containing a description of the pre study, development of new functionality and simulation of each new functionality.

4.1 Response system during up shifts

Common practice when shifting up is to press the clutch and release the accelerator pedal simultaneously, pull the shifter into next gear, release the clutch and reapply the accelerator pedal. When the accelerator pedal is let off in a vehicle with a turbocharged the throttle valve closes. The decreased flow of fuel and air causes a corresponding decrease of the exhaust energy driving the exhaust turbine. Since the turbo compressor consumes more energy than the exhaust turbine delivers the turbo speed decreases. A pressure peak after the compressor and an opening of the blow by valve, to avoid compressor surge, increases the energy consumed by the compressor further. Once the shifting procedure is completed, the accelerator pedal is pressed again and the throttle valve opens. The turbo has then slowed down and is not in its working speed range any more, resulting in that it has to accelerate to the speed necessary to deliver the desired boost for the engine. This results in a noticeable lag before the driver can feel the engine produce power again after the gear shift. According to Shinrak Park, Takaki Matsumoto and Nobuyuki Oda [5] another important factor in turbo lag delay is the decrease in efficiency due to physical properties of the turbocharger system.

The idea of a response system, or sometimes known as anti-lag system, is to eliminate lag by keeping the turbo speed high throughout the entire shifting sequence and thus never losing boost pressure.

The key to solve this issue is to avoid reducing the power delivered to the exhaust turbine by maintaining a high fuel and air flow through the engine. This can be achieved by requesting a high base torque and a low instantaneous torque from CVC, building up a torque reserve. A large difference in the two means that there will be a flow of air into the engine corresponding to the higher torque request while only achieving the lower request out on the crankshaft. The difference between the two described torques is referred to as a torque reserve. This difference is made possible by retarding the spark advance resulting in very low combustion efficiency. If the ignition efficiency can not be kept as low as necessary to reach zero or negative crankshaft torque some fuel cuts may be used. All the excess power has to be turned into heat and rejected into the exhaust in order to keep the crankshaft output low. This excess heat will also increase the enthalpy of the exhaust gas which in turn will help keep the speed of the turbine up. This process will only be active during the course of a gear change.

Tests were carried out in the chassis dynamometer to run the engine at a speed of 2000rpm with a very high torque reserve. These tests showed that it was possible to build substantial amounts of boost pressure while maintaining a low power output on the crankshaft. This can be seen in Figure 5.

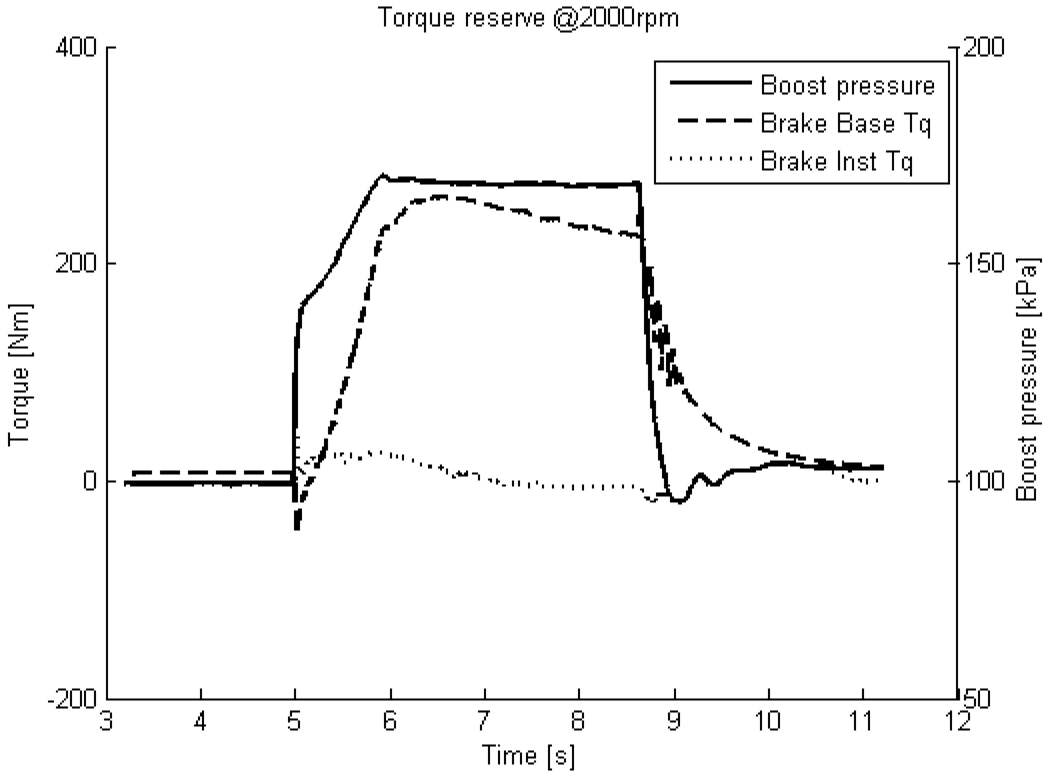

Figure 5 Difference between instantaneous and base torque when creating a torque reserve

Functionality to request a large amount of torque reserve while shifting gears was set up in CVC. The Simulink model can be seen in Figure 6. The model requests a low positive instantaneous torque request and adds a calibratable offset for the base torque request. The required inputs to activate the functionality are:

- That the driver keeps the accelerator pedal pressed below a calibratable threshold level while changing gears.
- The clutch pedal is pressed
- The engine and vehicle speeds are over a calibratable threshold level

A large torque reserve is then requested which will keep the flow through the turbo high, maintaining boost pressure but still allow the engine to not increase in revs. This will then eliminated the apparent lag felt after a gear change.

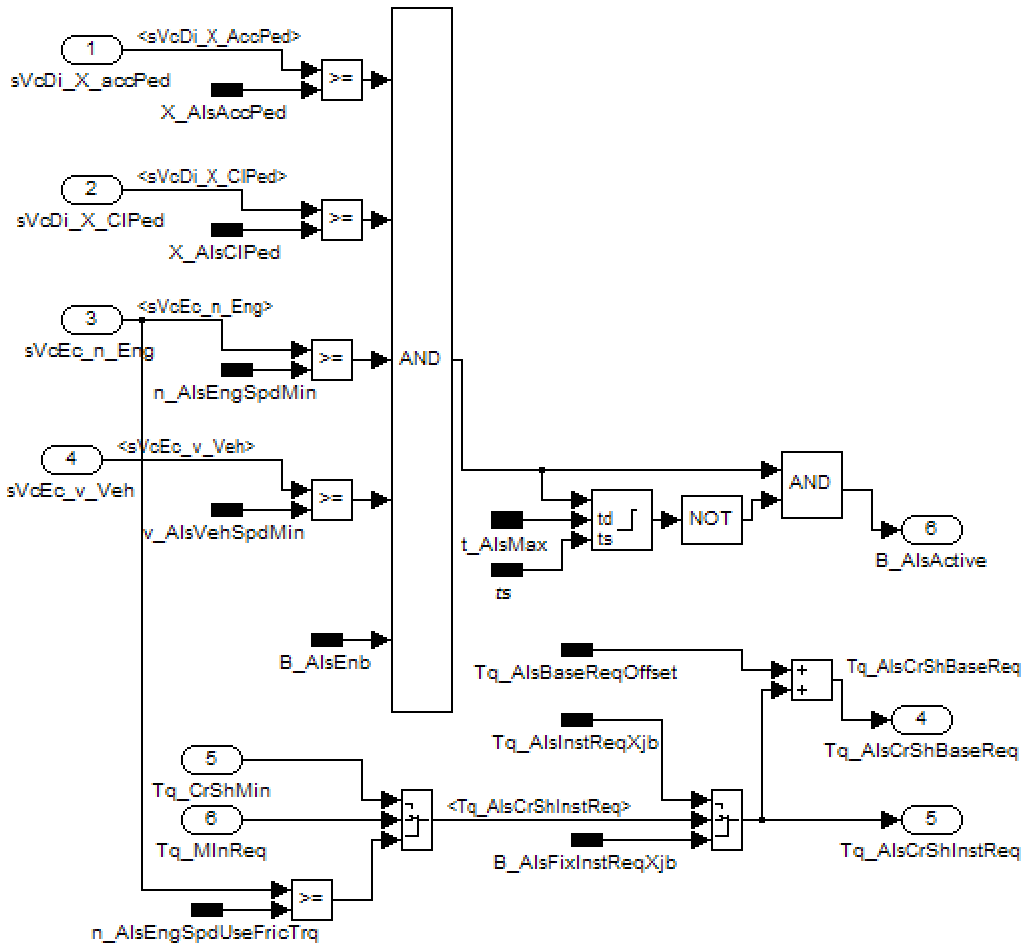

Figure 6 Response system

4.2 Launch control

The launch control chapter is divided into two parts, one for the scenario with manual transmission and one for automatic transmission.

4.2.1 Manual transmission

A launch control system is often used to get more accuracy during take off and fast accelerations from stand still when it is important to get a good start and to maintain a controlled wheel slip. The system lets the driver pay more attention to steering the car and change gear which makes it easier to get fast repeatable starts. These kinds of systems are often seen in race and rally cars but are getting more common in standard performance vehicles, e.g. Nissan GTR, VW Passat R36, and Chevrolet Corvette ZR1. Despite the more common use in performance vehicles this kind of system could, with some strategy modifications, also be used in a vehicle when driving with a caravan starting in a slope when it is crucial not to stall the engine. The setting of the system would then be less "race" oriented and more "driver aid" oriented.

Two sequential stages in time are identified during a launch situation:

1. Start 0-20km/h, need to overcome tire friction and driveline inertia to get the wheels to spin from stand still. It is not reliable due to engine characteristics to control towards a certain slip rate at low speed and instead the aim is a certain front wheel speed.

2. Vehicle acceleration.

    a. Deliver enough torque to overcome the inertia when accelerating the driveline and the vehicle

    b. Deliver the right amount of engine torque to generate the desired slip rate. The aim is to maintain the slip that corresponds to maximum longitudinal tire force.

In stage 1 it is also important to take the clutch capability to transfer torque into account. The amount of torque possible to transfer is dependant on the pressure applied on the clutch disc by the pressure plate. From this it is necessary to have a model in the launch control describing the torque transfer dependent on the clutch pedal position. If the torque on the crankshaft is higher than the torque the clutch can transfer the clutch slip will increase shortening the life span of the clutch disc. In a launch control system aimed for production, a function guarding the clutch slip rate is probably necessary.

The mu-slip curve for the tires used on the vehicle the launch control system will be tested on is in Figure 7 it is showed that the highest longitudinal force is achieved at a slip of 15%. The mu-slip curve is based on a normal load of 4000 N which represent the load on one tire. Since the change on this curve from varying the normal load between 3000N and 5000N is small, the curve in Figure 7 is used for the simulations in VSim.

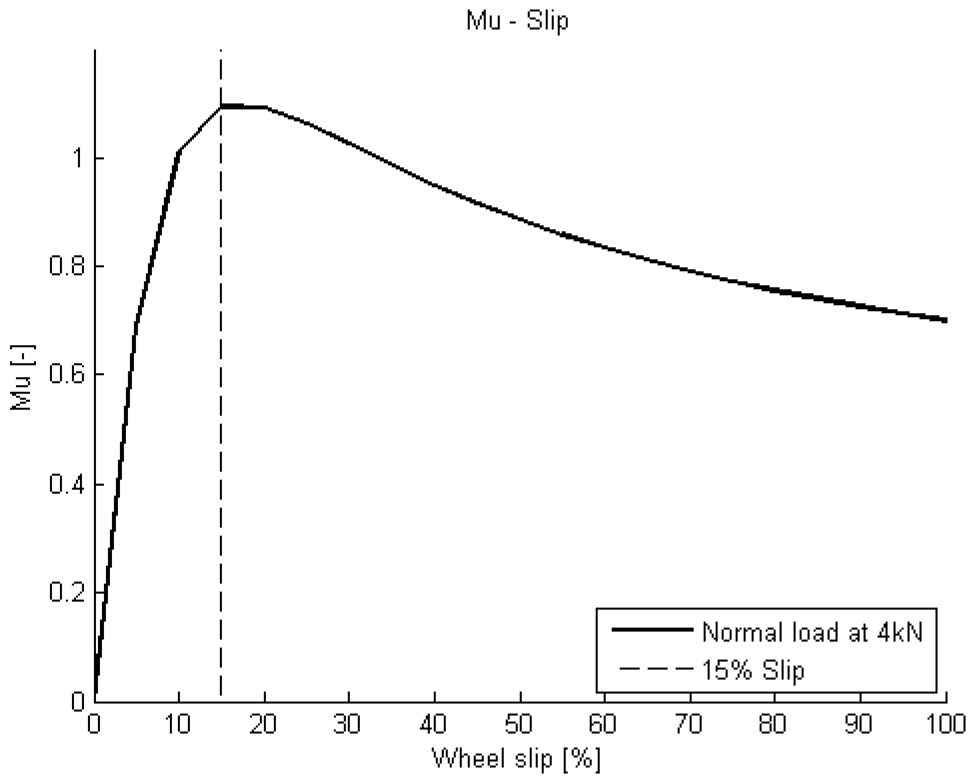

Figure 7 Mu-slip curve for a normal load of 4kN

4.2.2 Control strategies

To get a good control strategy the physical equations governing the system are derived. In VSim the vehicle dynamics during longitudinal motion is calculated. Since the launch control is based on a feed forward strategy it is important to describe the components that the engine output torque need to overcome, in terms of friction and moment of inertia. These components are the engine internals, clutch, gearbox, final drive, total gear ratio, drive shafts, brake discs, wheels and tires. To be able to calibrate this model in the EMS software the calculated torque demand is replaced by a calibratable table with time and surface friction dependant torque. This resulted in two models one with physical equations describing the system and one final version based on tables derived from the physical equations.

The first model is based on the physical equations of the systems describing inertia and friction of the vehicle during longitudinal acceleration. This model contains the stages described in chapter 4.1. When entering launch mode the vehicle is at stand still, first gear is selected, the clutch and the accelerator pedal are pressed. The first thing that is activated is setting the engine to the right speed and demanding a torque reserve. The engine should at this stage have enough stored energy and built up torque reserve so that when the clutch is released the wheels should start to spin. This is when the wheels and all other components between the engine crank shaft out to the joints at the wheels start to accelerate. The part up to 20 km/h is where the angular acceleration is at its largest and therefore is the effect of the moment of inertia in the components at its maximum. This stage is maintained until the rear wheels have reached 20 km/h and the slip reaches approximately 15% since the front wheels are kept at 23 km/h.

The equation describing this stage is in equation (7) which is a combination of equation (8) and (9). Equation (8) and (9) also represents the two parts in the second stage of the launch control.

When the vehicle is at 20 km/h the second stage comes into play. This stage is delivering the torque request from 20 km/h and until the acceleration ends or until there is not enough torque in the engine to maintain the wheels at 15% slip. Equation (8) and (9) describes the inertia and the wheel force respectively that results in a torque request to the engine.

$$Tq_{dynamic,2} = \frac{S_{tgt}\dot{\omega}_{rwhl}J_{fwhlaxle}}{i_{tot}^2} + \dot{\omega}_{eng}(J_{gearbox} + J_{flywhl,clutch,eng}) + \frac{N_F \mu_F r_{tire}}{i_{tot}} \quad (7)$$

$$Tq_{dynamic,1} = \frac{S_{tgt}\dot{\omega}_{rwhl}J_{fwhlaxle}}{i_{tot}^2} + \dot{\omega}_{eng}(J_{gearbox} + J_{flywhl,clutch,eng}) \quad (8)$$

$$Tq_{státic} = \frac{N_F \mu_F r_{tire}}{i_{tot}} \quad (9)$$

In the equations above S notes slip, J rotational inertia, r radius and i gear ratio.

The control strategies are based on a feed forward control system that requests torque depending on vehicle parameters and the surface condition. To get the right addition of the torque needed from the engine to overcome the inertia in the rotating parts in the powertrain a table, see Appendix B, of an estimated front wheel acceleration is used. This table is derived from physical models of the vehicle and the surface conditions, which results in a theoretical vehicle acceleration that is recalculated to a torque request. This means that no sensors or feed back are used. The strategy was first tested in VSim with the two stages separated in order to se how much each stage added to the total torque request.

From the slip target it is possible to get the friction coefficient from the mu-slip table derived from the tire data for the vehicle used in this project, Figure 7. With the friction coefficient and the normal load on the front wheels the tire longitudinal force is calculated. This is done with equation (4). To maintain this force it is necessary to deliver torque from the engine corresponding to that amount of tire force, this is done in equation (9). The inertias of the different components are seen in Appendix B in table B1.

With tire data and the correct friction coefficient this calculated torque should result in reaching the slip target. However the surface friction in reality is not as perfect as in the models and other simplifications make it necessary to have a close loop controller compensating the estimated torque request with respect to the difference between the target front wheel speed and the received real front wheel speed. The controller used is a PID (proportional enhancement, integration, derivation) and the controller parameters are set from testing in VSim.

The second and final model is based on the first model using the calculated torque necessary to maintain 15% slip during an acceleration. The physically derived feed forward torque is conveniently stored in a look up table with time and mu on the axis.

This gives the possibility to calibrate the feed forward part exactly according to the physics. But since the physics are simplified, this solution gives the possibility to fine tune the feed forward torque if found necessary during vehicle tests and calibration. A comparison between the total torque request from the feed forward model and the torque from the accelerated components is shown in Figure 8. The torque needed to overcome the inertia in the system is small compared to the total torque needed for the acceleration but it can not be neglected. The figure shows torque request for a 0 – 100 km/h acceleration. The steps are first, second and third gear. Only torque during the acceleration phase is shown, not the torque needed initially to get the wheels spinning.

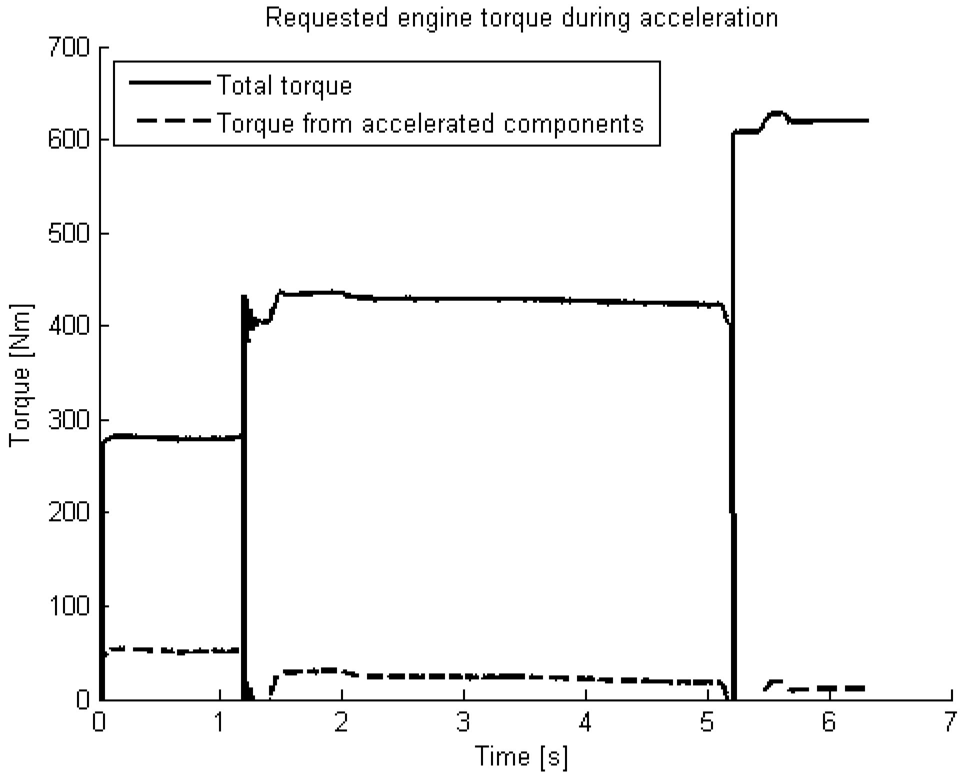

Figure 8 Comparing the total torque request with the torque needed to accelerate the powertrain components.

The model is based on a pre set value of the friction and then this is compensated before the next launch, the pre set value was wrong. The compensation is based on how much the controller worked to reach the slip target during the previous launch. The controller engages from the take off but initially it aims at a pre-set front wheel speed of 23 km/h since it is not possible to control against slip at low speed. Above that speed the controller starts to control against slip and it does that the rest of the acceleration duration except during gear change when the clutch is engaged. In Figure 9 and Figure 10 the feed forward model and the PID controller respectively are seen.

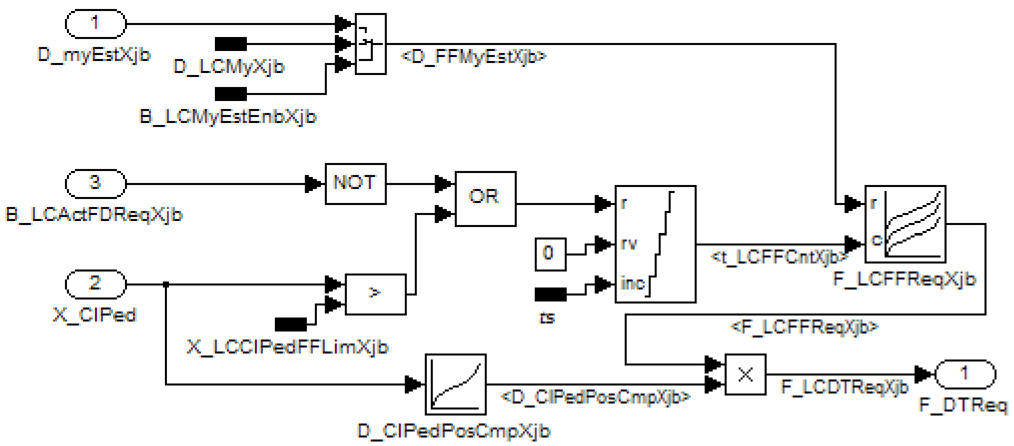

Figure 9 Launch control feed forward block

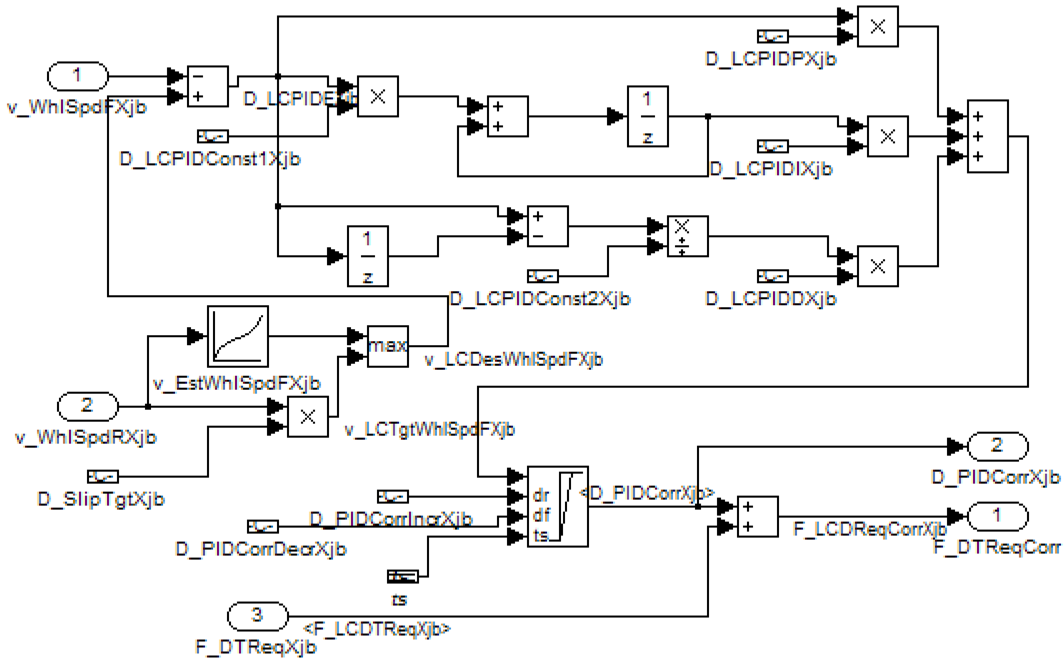

Figure 10 Launch control PID controller

The final results from the simulations with the second model are seen in Figure 11 and Figure 12. The figures show wheel speed and tire slip respectively. In Figure 11 the rear wheel speed can also represent the vehicle speed and from that it can be noted that the vehicle acceleration time 0-100 km/h is decreased from 7.98 to 7.62 seconds. In the acceleration without the launch control system the driver model in VSim is configured for full throttle accelerations and it does not compensate for wheel slip. This is seen in Figure 11 with a lot of wheel spin both in first and in the beginning of the second gear. The same configuration for the driver is used in the acceleration with the launch control active. The real S80 completes the 0-100 sprint in 7.5 seconds but since the aim with VSim for this thesis is to test and tune the launch control system no deeper studies has been made to why this does not compare. The improvement is the important factor.

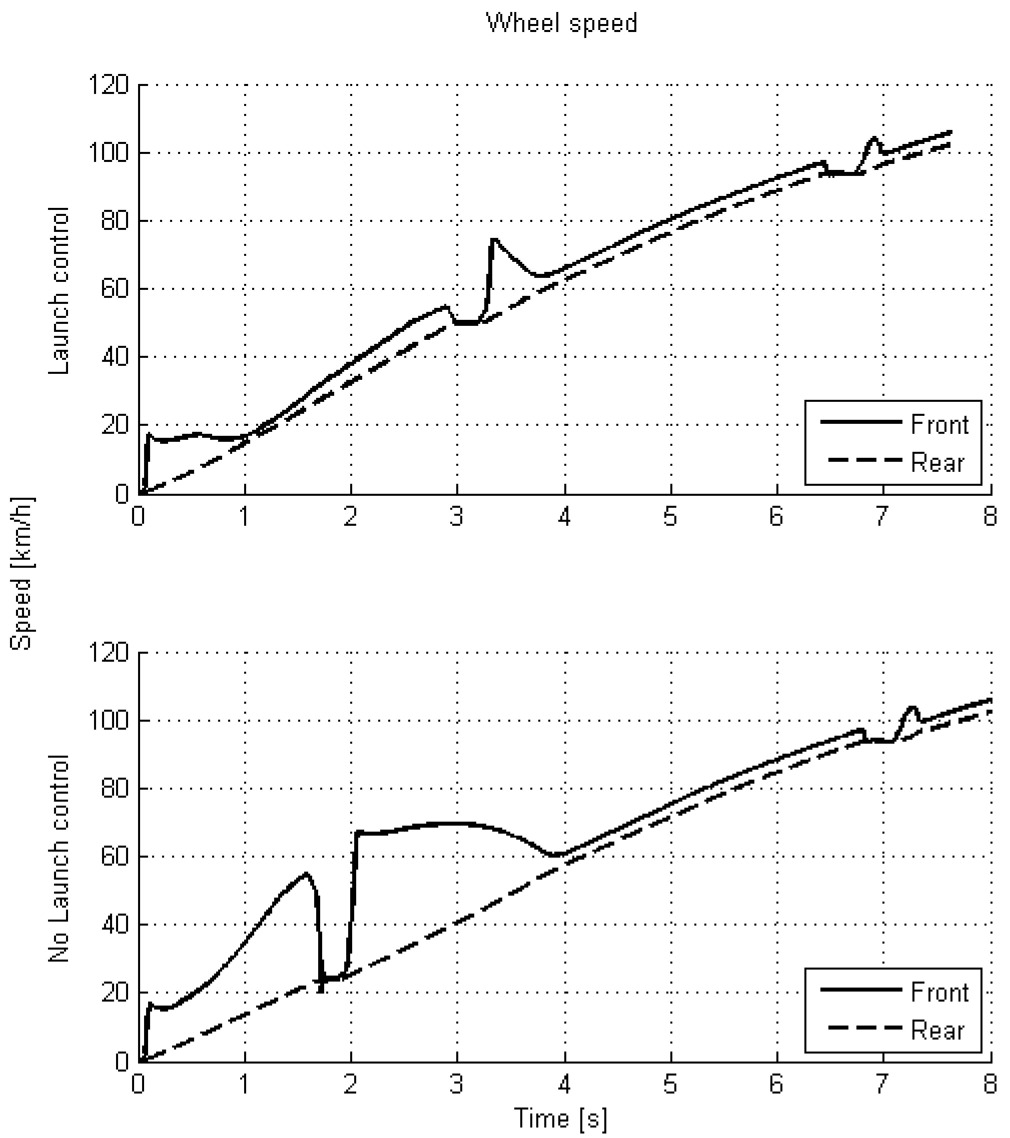

Figure 11 Wheel speed from simulations in VSim

From both figures the advantages with a launch control system is obvious and the wheel slip can be kept at the right level to generate as much longitudinal force as possible. The controller aims at a desired wheel speed in the beginning and then at about 20 km/h the target speed is replaced by a target wheel slip. In Figure 12 it is seen that the wheel slip target is reached in approximately 1.5 seconds from the take off. It is also seen that the engine can not deliver enough torque to generate the desired the wheel slip from the second gear. The gear change from first to second gear is at about 1.8 seconds without launch control and at about 3.3 seconds with the launch control. In this simulation the driver model changes gear when a target engine speed is reached. The launch control makes it possible to utilize the first gear in a better way.

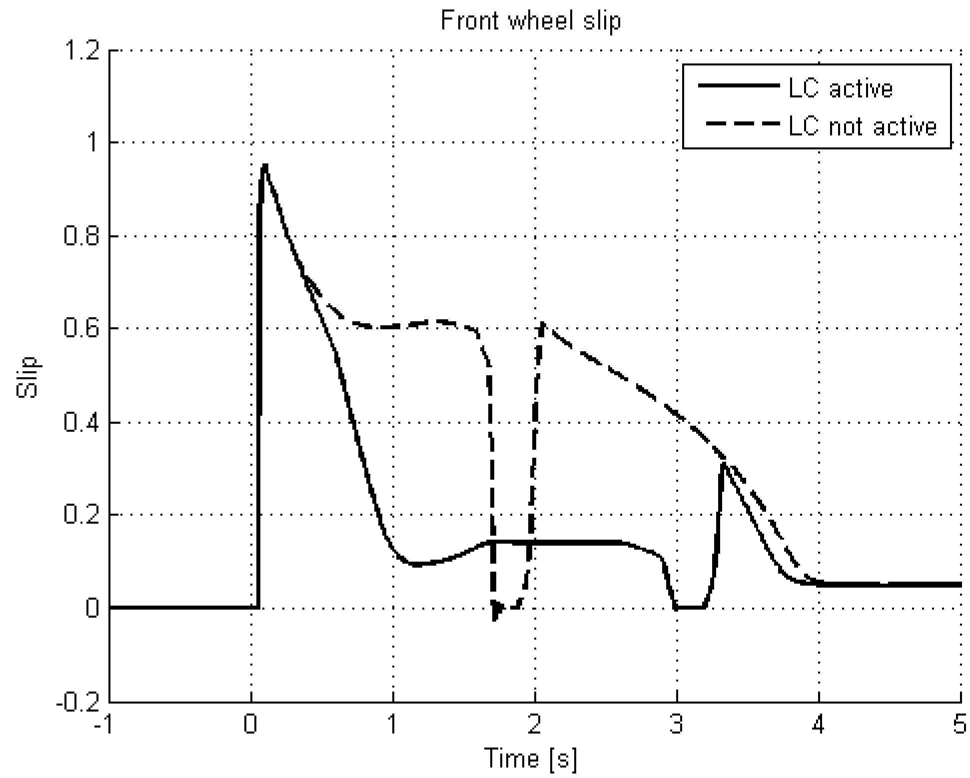

Figure 12 Front wheel slip from simulations in VSim

The overshoot seen in Figure 12 after the gear change both with and without launch control is because the engine has an elevated speed that is faster then the gearbox speed. This speed difference results in an addition to the feed forward control torque request and causes the wheels to have a larger slip after the clutch is released.

4.2.3 Automatic transmission

A car with Automatic transmission sets different demands on the launch control during take off since the transmission is stalled before take off in a launch situation. When the vehicle stands still and the driver presses the throttle pedal and applies full brake at the same time, stalling the automatic gearbox. The pump in the converter rotates with the same speed as the engine and the turbine stands still. This pressurizes the oil in the gearbox and special guiding vanes mounted on a free wheeling part, redirect the oil flow resulting in an amplification of the torque from the engine out to the wheels. When the pump speed and the turbine speed evens out the torque amplification decreases and disappears. The amplification is about two times during a stall situation.

Since the brakes are applied during a stall all torque amplified in the converter is handled between the brake pads and the converter. To make sure the driveline withstands this, torque out from the engine is limited. This means that during a regular stall the engine only produces a limited amount of torque and this is regulated with the throttle resulting in a low turbo speed and a noticeable lag when the brake pedal is released. During this situation the idea is to demand the limitation in instant torque and a larger amount of base torque creating a reserve. The base torque amount is possible to calibrate.

When the brake is released a FWD automatic transmission vehicle could probably use the same launch controller as a manual transmission vehicle, except for a slight adjustment to compensate for the torque amplification.

4.2.4 All Wheel Drive

For an AWD vehicle the controller is unnecessary since the engines in Volvo cars today do not produce enough power to receive large amount of wheel slip on all wheels. There is also no reference wheel speed to regulate against if the initial feed forward demand is wrong. In this case the vehicle speed would have to be calculated from an acceleration sensor, as used by the ESC during TractionControl and ABS, or a GPS sensor.

4.3 Down shift support

The problem when downshifting hard at high engine speeds the vehicle stability is compromised. The wheels can almost lock up after engaging the next, lower gear since the engine speed has to be accelerated very fast. This may not be noticeable to the average Volvo buyer but the more race oriented driver will notice. It is especially noticeable in scenarios where high power cars enter corners at high speeds on the very edge of their maximum capabilities. Another reason to enter an automated functionality of this sort in to a standard vehicle is to transmit the feeling of sporty driving and a thrilling ride.

The down shift support was first tested by doing a recalibration of the already existing GSH, Gear Shift Harmonization, which is already in production. The aim of the GSH is the opposite of the down shift support. When up-shifting the GSH prevents the engine revs to drop lower than to the matching revs of the next higher gear. The functionality is created using a look up table of gear ratios. The target speed is then calculated as that of the ratio of the next gear. This table was recalibrated to match that of a lower gear instead.

After successful testing new logic block were added to interpret if the next gear will be up shift or downshift. The system always assumes that the driver will not skip gears. Default setting is to expect an up shift. When either of the following criteria is true, the next change of gear is expected to be a downshift.

- Brake pedal applied

  When the driver has one foot on the brake pedal it is assumed the intention is to slow down, hence it is assumed that the next shift will be to a lower gear.

- Accelerator pedal above threshold

  If the driver was to do this maneuver manually he would need to apply some gas in order to get the engine revs up. When a driver applies gas during a shift it is then assumed that this is what he is intending to do, and the functionality is activated to aid in matching the engine and gearbox speed. This is especially handy when driving and planning to overtake the vehicle in front. The driver then wants to downshift but not slow down, which means the brake pedal criteria would be faulty here

- Highest gear engaged

  If the current gear is the highest gear the only way to shift is to downshift, which means the functionality can be activated using these criteria.

4.4 Combustion control for exhaust detonations and skip stroke

4.4.1 Skip stroke

The theory behind the skip stroke and exhaust detonation process comes from the reasoning behind the combustion process in a spark ignited internal combustion engine. Input on the behavior of such engines has also been contributed by Volvos SI engine specialist Fredrik Wemmert at the department of Engine control and calibration. No simulations on the combustion phenomena were made before starting to develop these functions.

The functionality for exhaust detonations and fuel cuts for skip-stroke need to be implemented both in CVC and in the engine controller. The control logic and triggering functionality belongs in the CVC software and the functionality to cut fuel and ignition are implemented into the engine controller. The reason for the latter is that these functions need to run on a combustion synchronous time raster in order to be executed every engine cycle, which only is possible within the engine controller. Modern engine control systems are very large and complex hence the decision was made to put the new functionality at the end of the process chain, that is right before the information is sent from the engine controller to the platform that tells the actuators to perform the desired action. The reason for doing so is that the chance of other functionality disrupting the desired results is minimized. However, precaution has to be taken since this also means that the new functions are placed after any over-heat compensation, knock protection or other safety functions. Access to Denso's engine strategy models was obtained and the new functionalities were added to it. After making and simulating the new functionality it was sent over to the Denso office for validation and compilation.

In order to run the engine in skip stroke mode it is needed to cut every other injection, making the engine turn four revolutions between every combustion for each cylinder instead of two. This was done by adding logic to the block that calculates the injector opening time to get the appropriate amount of fuel into each cylinder. The logic for how much fuel to inject can be seen in Figure 13. Note that all Denso specific blocks are removed due to confidentiality and only inputs and outputs relating to the new functionality are shown. Essentially what is done here is that the injection time is multiplied by zero when a fuel cut is wanted. From CVC two signals are sent to the fuel cut logic, one to set it active and the other specifying the desired cut interval. The interval value is interpreted such that one injection in the given interval will be omitted. Since an interval is specified this means not only 8-stroke but any stroke can be realized. The hold logic is used to ensure cut of an entire injection.

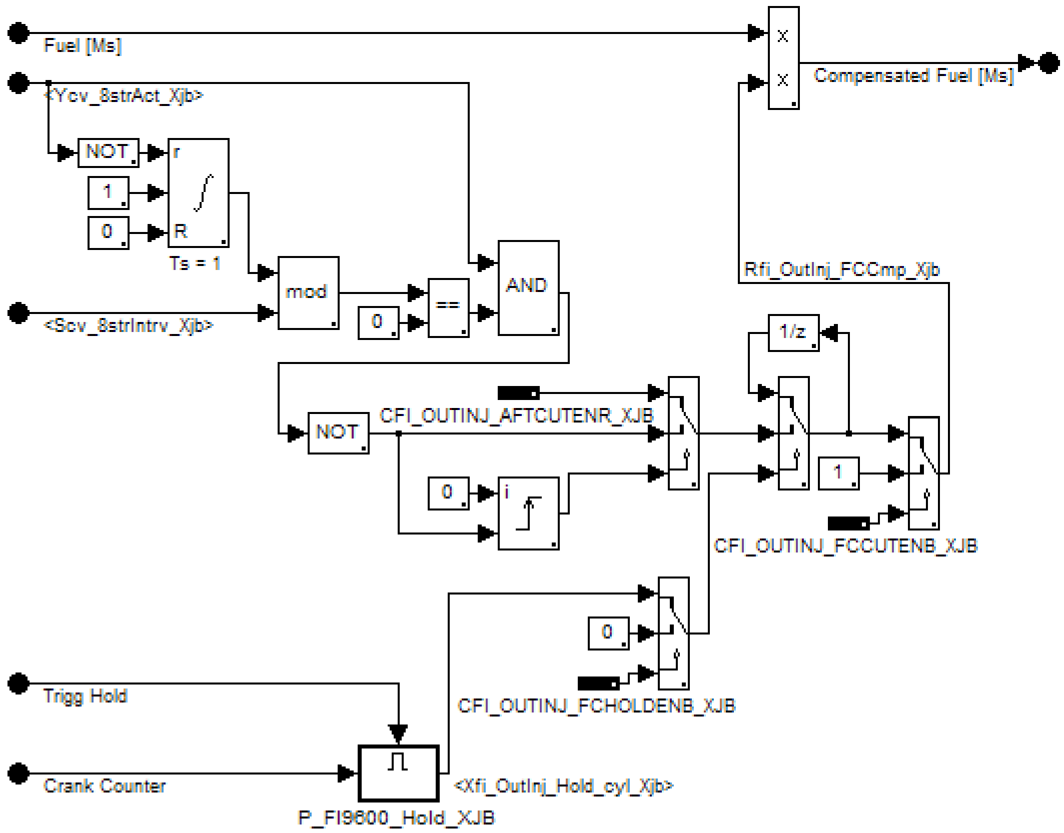

Figure 13 Fuel cut logic

4.4.2 Exhaust detonations

To get a detonation in the exhaust system fresh air/fuel mixture needs to be present in the exhaust and then ignited. This is done by cutting the ignition while maintaining fuel injection over a period of engine cycles. The logic to do ignition cuts in order to get fresh air/fuel mixture into the exhaust is based upon similar thinking as that of the skip-stroke logic. The difference being that here it is desired to cut a given number of ignitions in a row in order to get the proper amount of mixture into the exhaust. For skip stroke it is not desired to get fuel into the exhaust, therefore fuel is cut. Functionality was also added to alter the target lambda value while the ignition cut is active. This mixture will then be ignited by a late spark directly following the ignition cuts. The angle of this spark can be calibrated. It is also possible to specify how many times to repeat this sequence in order to cause more than one exhaust detonation. To cut the ignition the dwell time is set to zero. The functionality added to the Denso blocks can be seen in Figure 14.

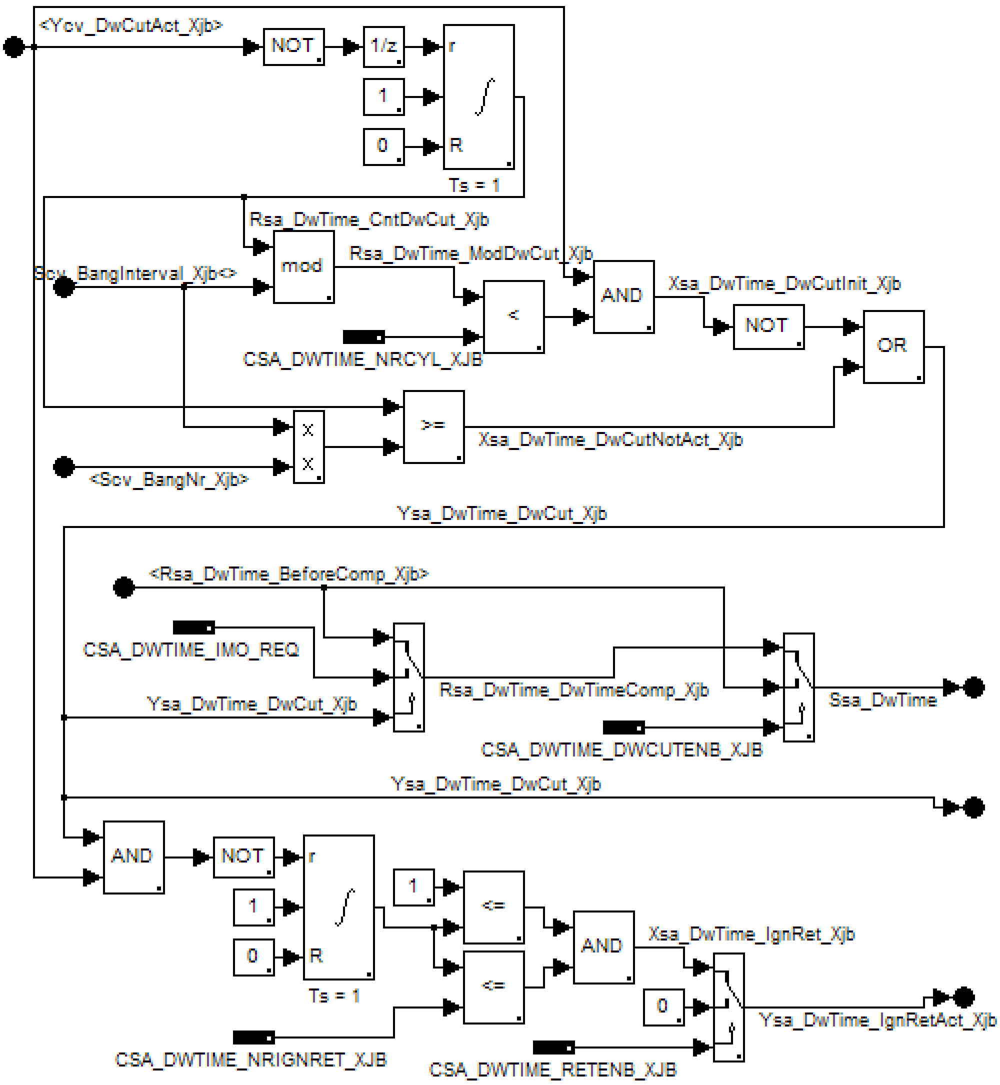

Figure 14 Ignition cut logic

There are two ways to activate the exhaust detonations, at accelerator pedal lift off or when changing gears. The criteria for detonation at lift of are:

- The rate of change of accelerator pedal position is negative and below a threshold level
- The engine speed is over a threshold level

The criteria for exhaust detonation when shifting are:

- Engine speed over a threshold level
- The clutch pedal is pressed below a threshold level
- The vehicle speed needs to be over a threshold level
- The throttle pedal is released

4.4.3 Simulation

To simulate the functionality of the exhaust detonation and skip stroke logic measure data for all the inputs and outputs for the injection time and dwell time functions were recorded in a vehicle at a couple of different operating points. The recorded data was imported into Matlab and then run through the Simulink functions. First time with the new functionality for cut was turned off in order to validate that the simulation outputs corresponded to the output data from the measurements.

After validation the added functions are turned on and the data analyzed. It is possible to see that the fuel or ignition will be cut but the resulting combustion phenomena can not be simulated this way. The simulation results are used to verify that the added functionality works in terms of generating the intended outputs. A simulation of the fuel injection with every third injection cut of can be seen in Figure 15. The dashed line represents the injection time in milliseconds and the solid black pulses represent the start of where an injection is supposed to take place. The five graphs each represent a cylinder, sorted in the firing order. The first injection right after a fuel-cut is enriched, which can be seen by the longer injection time, to compensate for the previous injection cut.

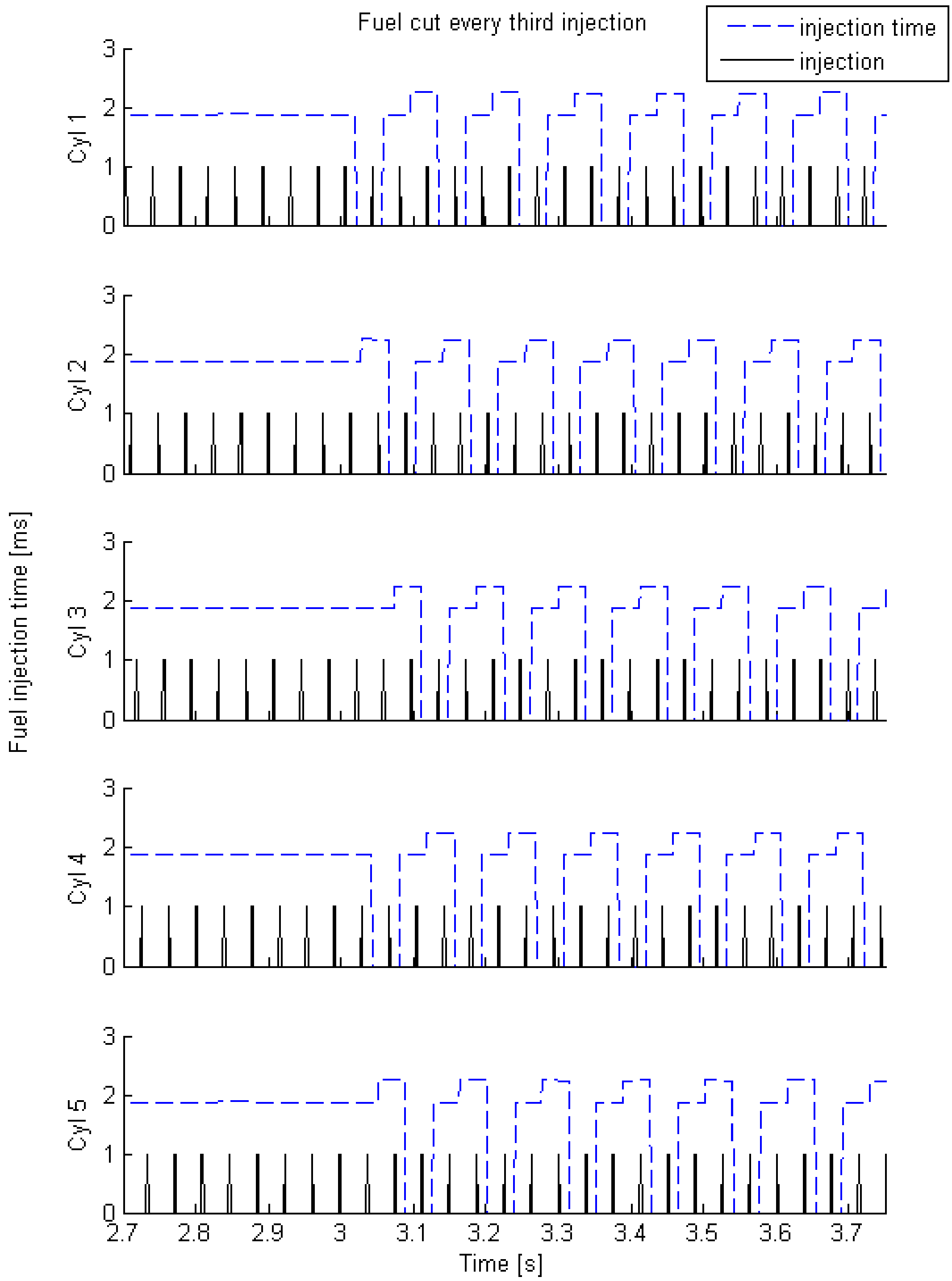

Figure 15 Simulation of the skip stroke model

The result of the dwell time cutting logic simulation can be seen in Figure 16. The simulation output shows when the dwell time is set to zero (cut) and the retardation of the following spark angles. A scenario with three cuts is shown, which is intended to cause three exhaust detonations, each ignited with the late sparks directly following the ignition cuts.

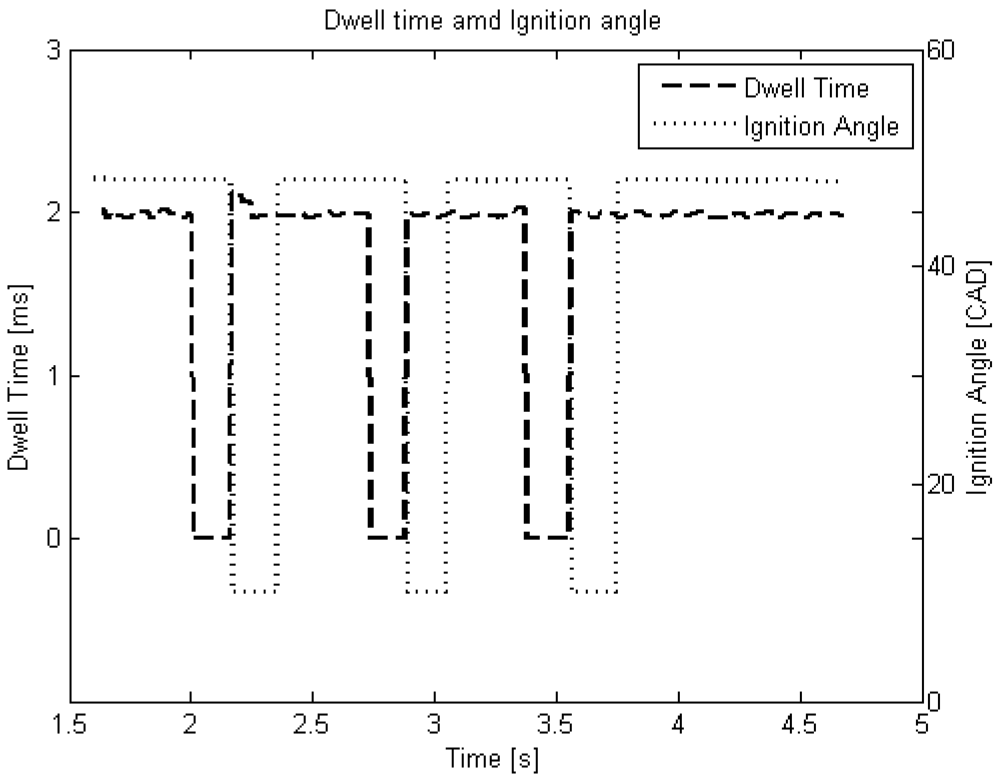

Figure 16 Ignition angle and dwell time

4.5 Throttle response in neutral

The pedal characteristic functionality is a feature that mainly concern how the vehicle is perceived by the driver. The only way to get feedback on it is to ask the driver how it feels. A problem here is that the driver who expects a sporty response from the engine perceives the throttle response when in neutral as unsteady and not very precise. This is due to how the accelerator pedal position is interpreted by the engine controller. Within the engine controller there are pedal maps that convert the throttle pedal position to a torque request to be realized by the engine. In Figure 17 a pedal map can be seen. Only a select number of accelerator pedal positions are shown for clarity.

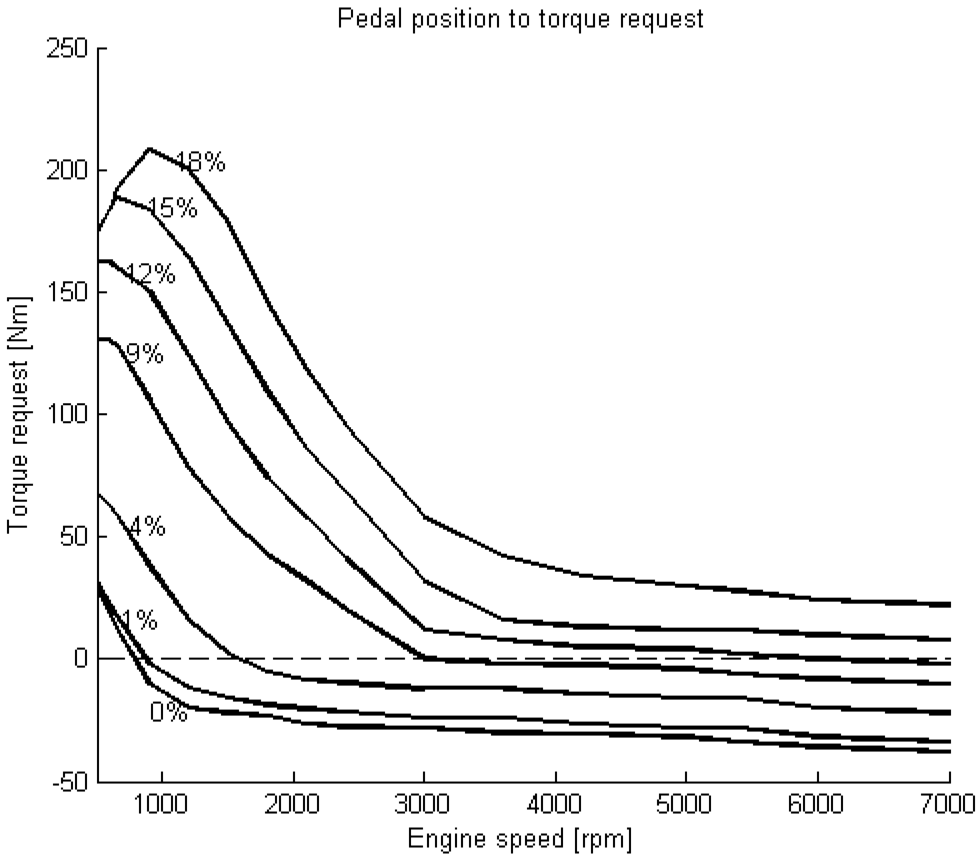

Figure 17 Accelerator pedal map, each line represents an accelerator pedal position

When idling the torque request is essentially zero since no useful torque is needed out on the crankshaft, except to overcome friction and drive auxiliary devices. The engine speed ends up where the delivered torque is equal to the friction torque. This means that the engine speed will be steady when the lines in the graph cross the X-axis. When the lines cross zero in Figure 17 however, they have a small gradient which results in the throttle pedal position interpretation being very close to zero torque request at a range of engine speeds, resulting in this imprecise feel of the pedal. This can be regarded as a P controller where the gain in this case is low.

In order to solve this an additional pedal map was added to the system. This new map only goes active when the car is in neutral. It has a much steeper gradient of the torque request at the crossing of the zero request line, resulting in the engine operating at a steadier speed since any increase in engine speed will decrease the torque request significantly and vice versa. This can be seen as a higher controller gain. Having a higher and flatter torque request up until the desired speed is reached also results in the engine accelerating faster, with the risk of overshooting if the torque request is to high for to long. An example of a pedal map for neutral gear can be seen in Figure 18. Note the steep gradient when crossing the zero line.

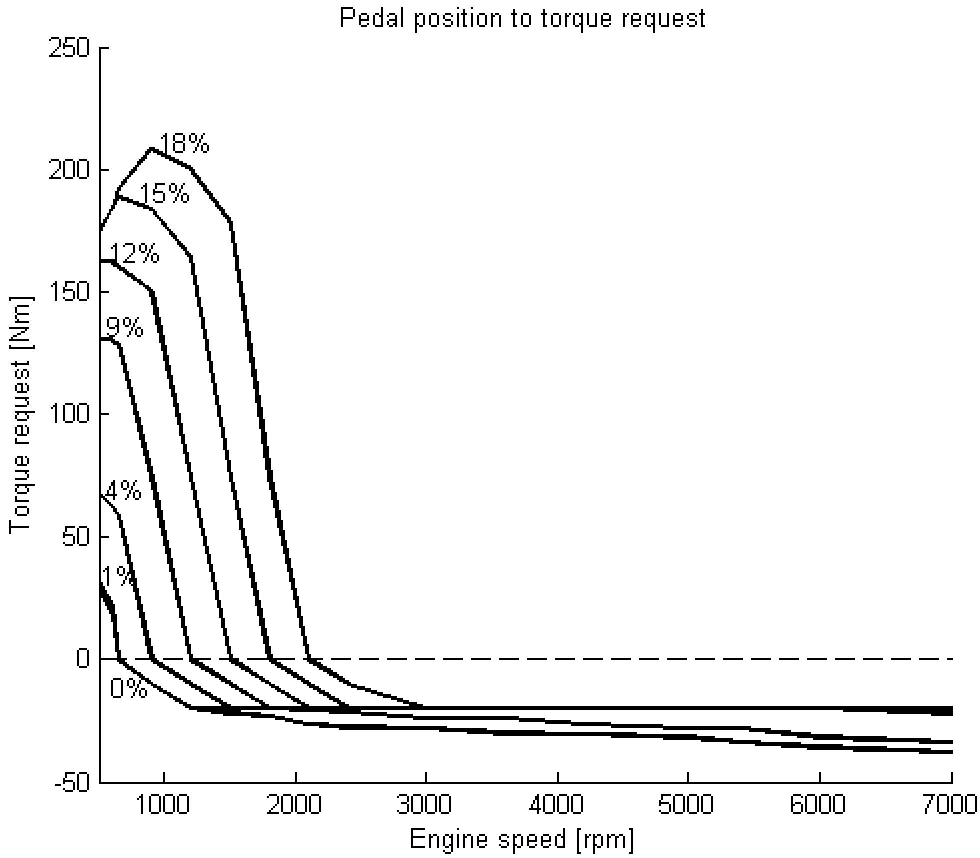

Figure 18 Modified accelerator pedal map, each line represent an accelerator pedal position

A map like this can not be used in a driving situation since it will cause the car to run as with a cruise control active, adding torque when engine speed goes down, but without the finesse of the cruise control, resulting in a jerky ride.

5 Vehicle testing and calibration

Testing of behavior and functionality of the features has been carried out in vehicles. Testing and data collection were done in the vehicles before changing anything in order to get a reference.

The car used for this project is an S80 with a 2.5 liter port fuel injected turbocharged engine. Since testing included high torque reserve demands, resulting in late combustion, over relatively long time periods it was known the exhaust would get very hot and there was risk for damage to the catalyst. The exhaust detonations were also deemed to be harmful to the catalyst so it was removed before testing started. Since the vehicle at hand had an automatic transmission it had to be rebuilt to manual transmission. This was done and resulted in some conflicting issues that had to be resolved before the car realized it no longer had a Transmission Control Module (TCM) to talk to but a clutch pedal instead.

5.1 Test procedure

The test procedure began with testing a standard vehicle in order to validate the current state of performance. For many of the new features some tweaks were done with the calibration in the standard set up in order to simulate the desired outcome before any new functionality has been implemented.

Tests have also been conducted in the chassis dynamometer at VCC. The car was placed with the driving wheels on a rolling road that could be set at different speeds or do sweeps. Here it was possible to test different functionality in different scenarios in a controlled environment. Doing full load tests on an open road is both dangerous and it is difficult to repeat the same experiment twice. In the dynamometer a control box is used instead of the accelerator pedal in order to be able to control the pedal position accurately and to keep it perfectly steady. The control box also depicts the speed of the rollers.

The launch control functionality was tested initially on a gravel field in order to get a lower surface friction. This enabled longer wheel spins and more time to properly set up the controller parameters. The acceleration runs on asphalt were performed on the TT track at VCC.

5.2 Data collection

Most data has been collected using INCA connected to the ETK of the car. Data for the 0-100 km/h runs has been collected by Olof Daunius, Daniel Magnusson and Martin Ågren from the Powertrain Attributes department, using a Vericom VC-3000 Performance Computer, which is a professional grade data logging accelerometer.

5.3 Function calibration and modification

The calibration of the new functions was done in car using INCA. It can sometimes be an iterative process, for example when setting up the right conditions to cause an exhaust detonation or to get the launch controls controller gain set up properly. Generally a setting is put in, tested and measured and after validating the measure data a new setting is tested if the desired result is not achieved. At some points it was found that larger changes than only calibration were needed, for example it was noticed that some triggering functionality between functions conflicted with each other and therefore the models had to be altered.

6 Results

In this chapter the results from each feature are presented.

6.1 Torque reserve

The creation of torque reserve in itself is not a feature but it is a method that has been used to actualize a couple of the features and therefore deserves a section in the results chapter. The ability to create torque reserve is important in both take off situations and during gear shifts. This section describes the resulting torque reserve possible to create during steady state running conditions.

The results below are from tests carried out at 2000rpm engine speed. In one case with no engine load (suitable for take off with manual transmission or during gear change) and another case with an engine load of 180Nm.

6.1.1 Torque reserve with no engine load

The maximum amount of boost possible to create at this operating point is around 160kPa absolute pressure with a torque reserve of 275Nm. The pressure after the throttle valve was 140kPa. A graph showing the boost pressure and intake (after the throttle valve) pressure can be seen in Figure 19. Note that for all reserves the pressure to the intake is limited by the throttle valve, this means lost efficiency but a gain in response once the torque request is increased.

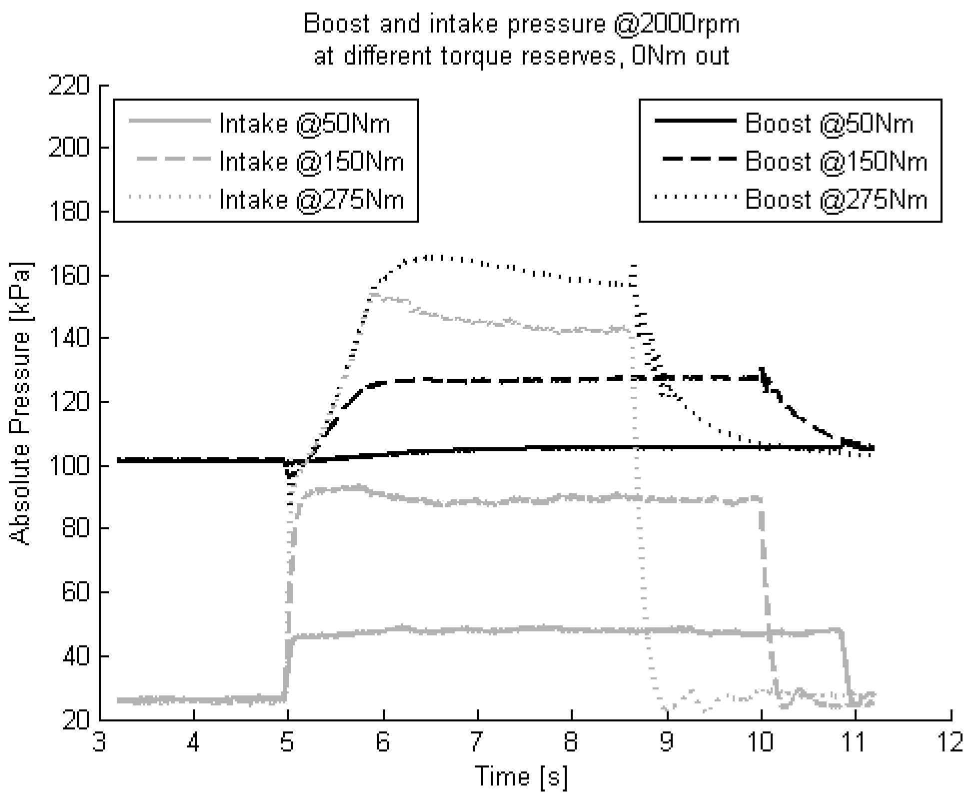

Figure 19 Boost pressure at different torque reserves

When performing the tests the spark retard limit was lowered in order for the engine controller to be able to adjust it freely. In Figure 20 the spark advance for different torque reserves is illustrated. The MBT timing is illustrated in grey and is normally around 30 degrees before TDC. When running with a 275Nm Torque reserve the spark timing is at more than 40 degrees after TDC. This is well below the normal retard limit which is at about -10 to -15 degrees. The engine ran remarkably well at this operating point considering most of the combustion takes place in the exhaust.

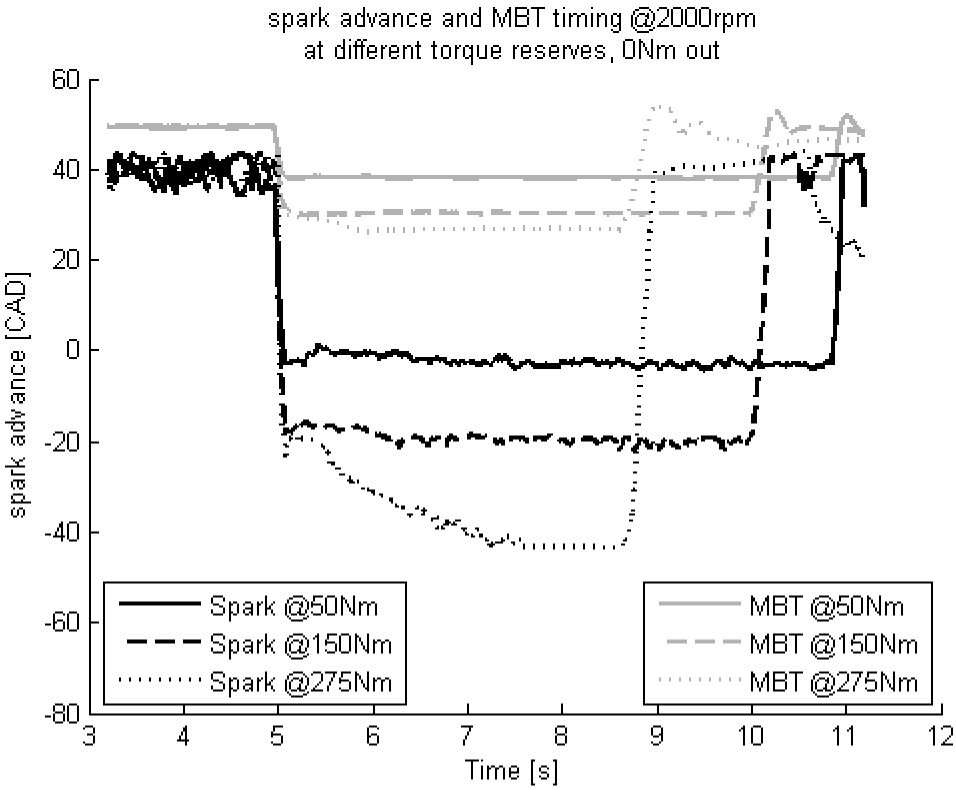

Figure 20 Spark advance at different torque reserves

The spark retardation causes the temperature in the exhaust to increase rapidly. This is illustrated in Figure 21. For these measurements one thermocouple was located in the turbine of the turbocharger and one in the catalyst. Note that the test vehicle was not equipped with a catalytic converter when the tests were carried out due to risk of damage. This means that the temperatures at the point where the catalyst originally would be mounted may be inaccurate due to differences in pressure and heat absorption capacity of the non existing catalytic elements. The tests were not carried out with the same initial exhaust gas temperature but it can be seen that the rate of the heat increase is larger when creating high torque reserves. Care must be taken not to operate at this point for long periods. It takes about four seconds to go from a 650°C turbine temperature to over 1000°C with the thermocouples used during the test. The real temperature dynamics are probably faster. To measure the temperatures more accurately special temperature probes are recommended. This type of measurement was not possible to fit in the scope of the thesis work

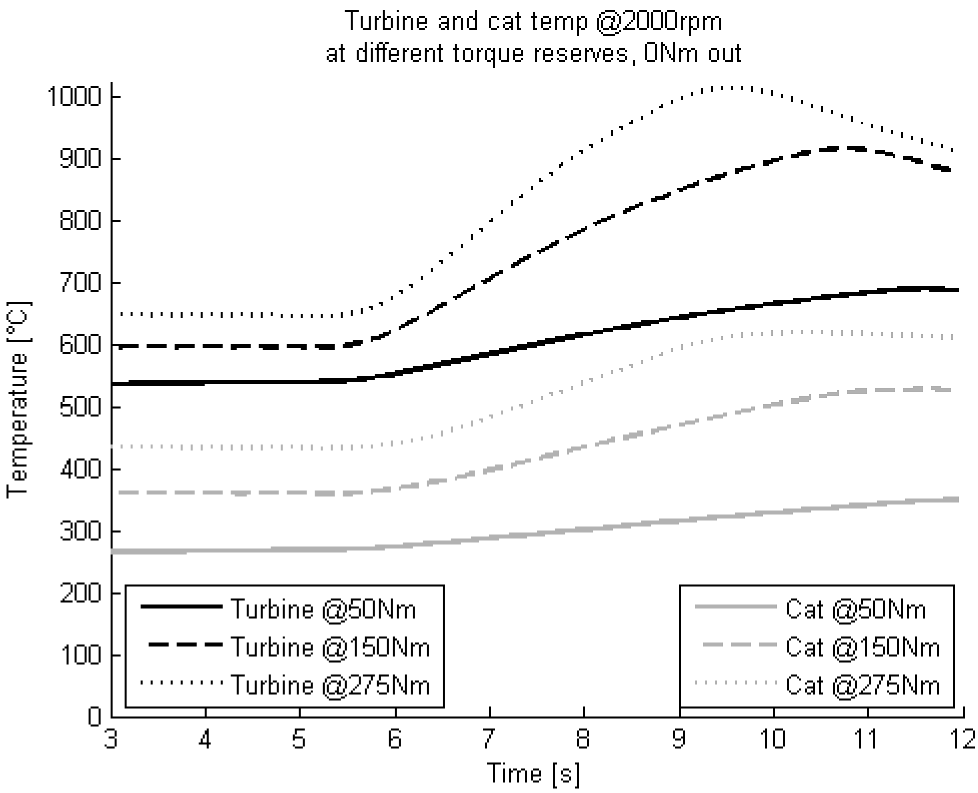

Figure 21 Turbine and catalyst temperatures at different torque reserves

The influence of the lambda value is also an interesting aspect in this load point. The influence of lambda value on temperature at a torque reserve can be seen in Figure 22. The tests were not carried out with the same initial exhaust gas temperature but it can be seen that the rate of increase is smaller when running at higher lambda values.

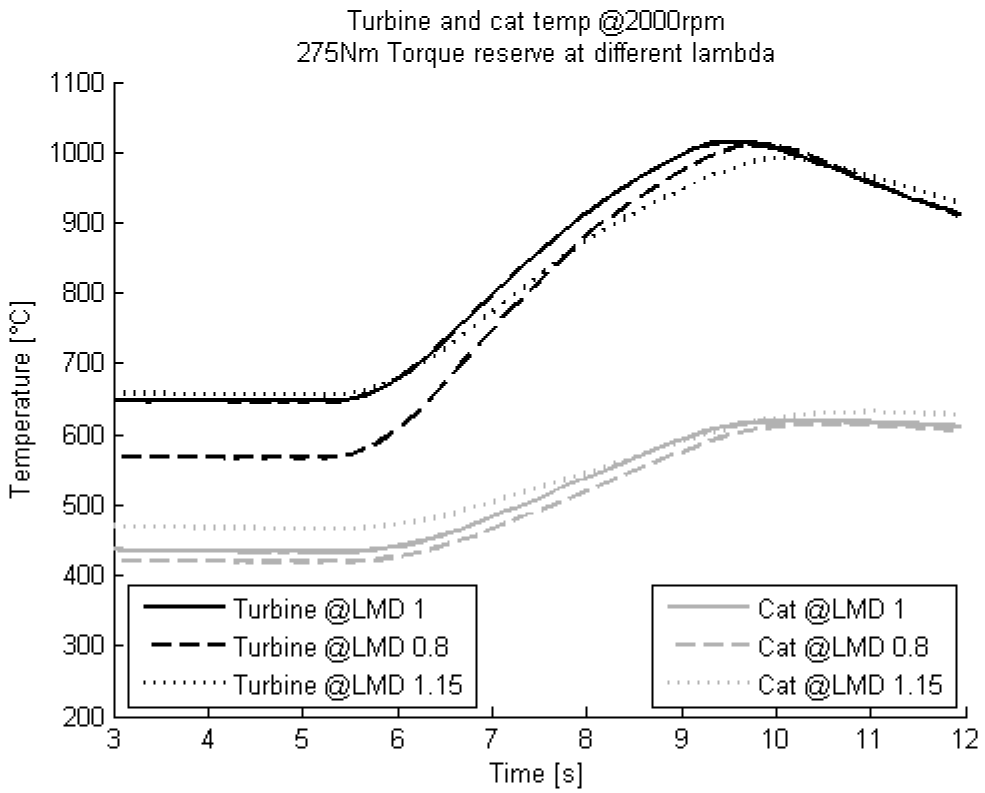

Figure 22 Lambda value influence on temperature at a torque reserve of 275Nm

The higher lambda value results in the engine trying to supply either more air to the combustion process or less fuel, since the engine is already operating with a base, or air, request corresponding to 275Nm the solution in this case is to decrease the amount of fuel injected. This result in less energy released and also that the spark timing can be advanced with maintained torque reserve, resulting in cooler exhaust gasses. The resulting spark timing can be seen in Figure 23.

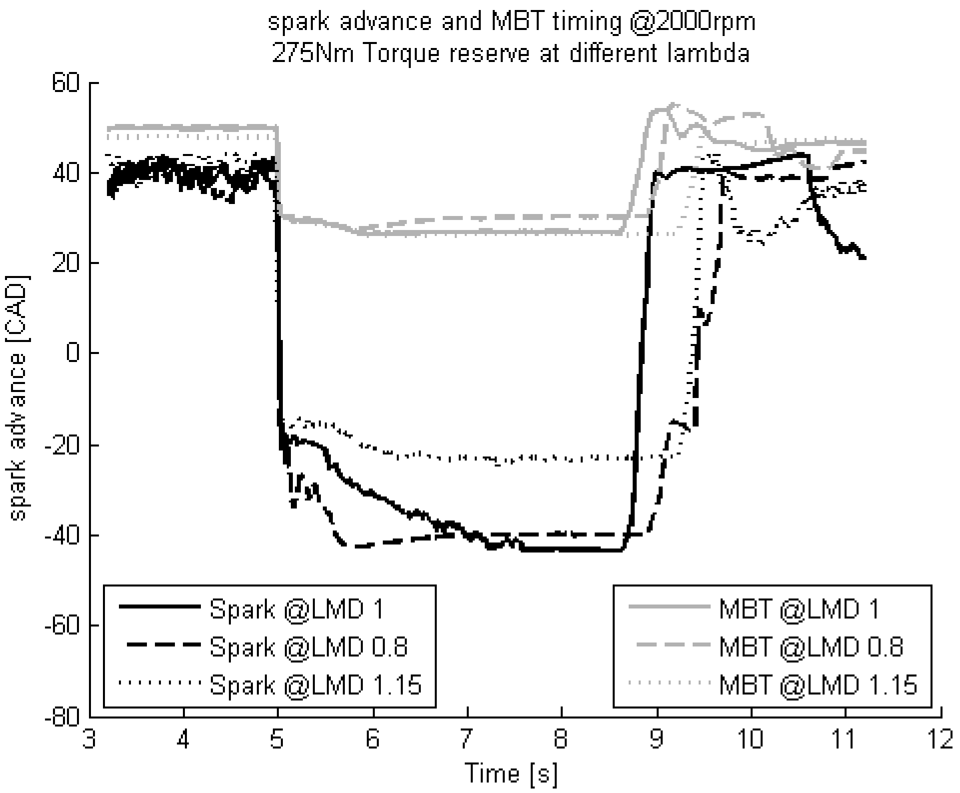

Figure 23 Lambda value influence on spark advance at different at a torque reserve of 275Nm

6.1.2 Torque reserve at 180Nm load

The following measurements were carried out on a chassis dynamometer running the engine at 2000rpm and 180Nm load. At torque reserves above 100Nm the engine starts to misfire. Boost levels can be seen in Figure 24, Spark advance in Figure 25 and temperatures in Figure 26. The reasoning of causes and effect is similar to those with no load, except that the engine misfire became obvious when loading the engine. The reason for misfire is at this point unclear but it is most likely a conflict between functions rather than that it is impossible to get more than 100Nm of torque reserve. A probable cause is that the ECM is allowed to alter both fuel injection and spark angle in order to fulfill the torque request. When the ignition angle hits the retard limit the compensation will instead be made by cutting fuel, resulting in what was experienced as misfire. The retard limit was not lowered when performing this test. Further investigation of the cases above 100Nm of torque reserve should be done.

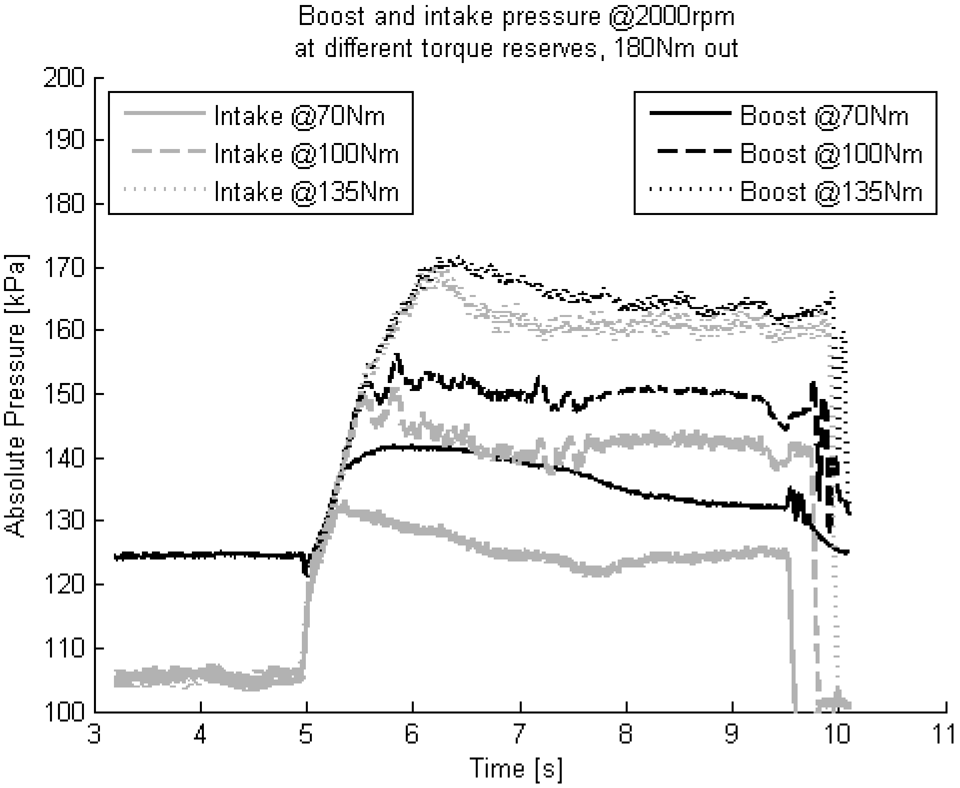

Figure 24 Boost pressure at different torque reserves with 180Nm load

The boost levels created here are just above 160kPa absolute pressure (170kPa for a short period in time). At load boost pressure comes at a lower torque reserve compared to the no load case. This is because during normal running at 180Nm the engine runs at a boost pressure of about 125kPa as can be seen for the first couple of seconds during the measurement in Figure 24. At a torque reserve of 100Nm a boost pressure of 150kPa is achieved in this load case compared to about 110kPa for the no load case. 160kPa seems to be the maximum boost pressure possible to create in the load case as well as the no load case. It is at the point of achieving this pressure that the engine starts to misfire.

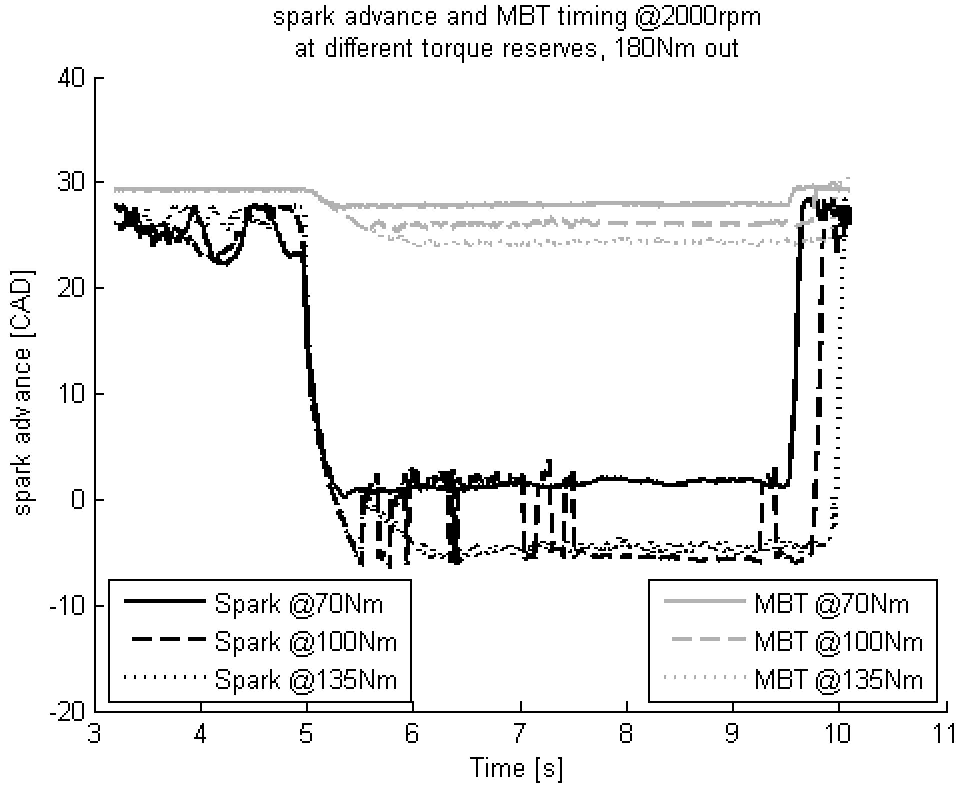

Figure 25 Spark advance at different torque reserves with 180Nm load

Note how the fluctuations in spark angle for the 100Nm run in Figure 25 are reflected in the temperature graph in Figure 26.

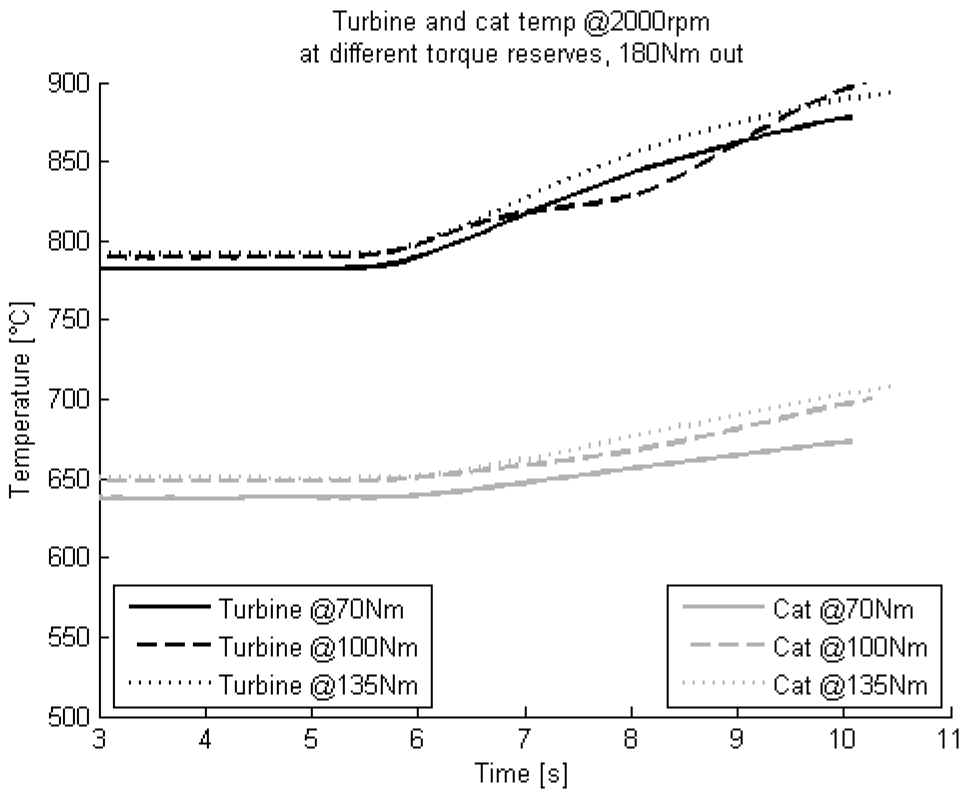

Figure 26 Turbine and catalyst temperatures at different torque reserves at 180Nm load

The influence of lambda value on temperature is similar to that in the case with no load.

6.2 Response system during up shift

The torque reserve presented above is used during gear change in order not to lose boost pressure. Doing so resulted in regaining the same level of boost after gear change in 0.3 seconds faster using the response system compared to a regular shift when the accelerator pedal is let off. The response system also prevents the boost pressure to drop below 160kPa absolute pressure, and if the system is used at a point where the engine is not creating high boost pressures it is lifted to 160kPa during the gear change. A gear shift using the response system can be seen in Figure 27. When the throttle valve closes during a gear change the pressure peaks since the turbo pumps air into a closed volume. This results in that the blow-by-valve opens bypassing air from the high pressure side to the low pressure side, resulting in a pressure drop. This is clearly represented in the standard case in Figure 27.

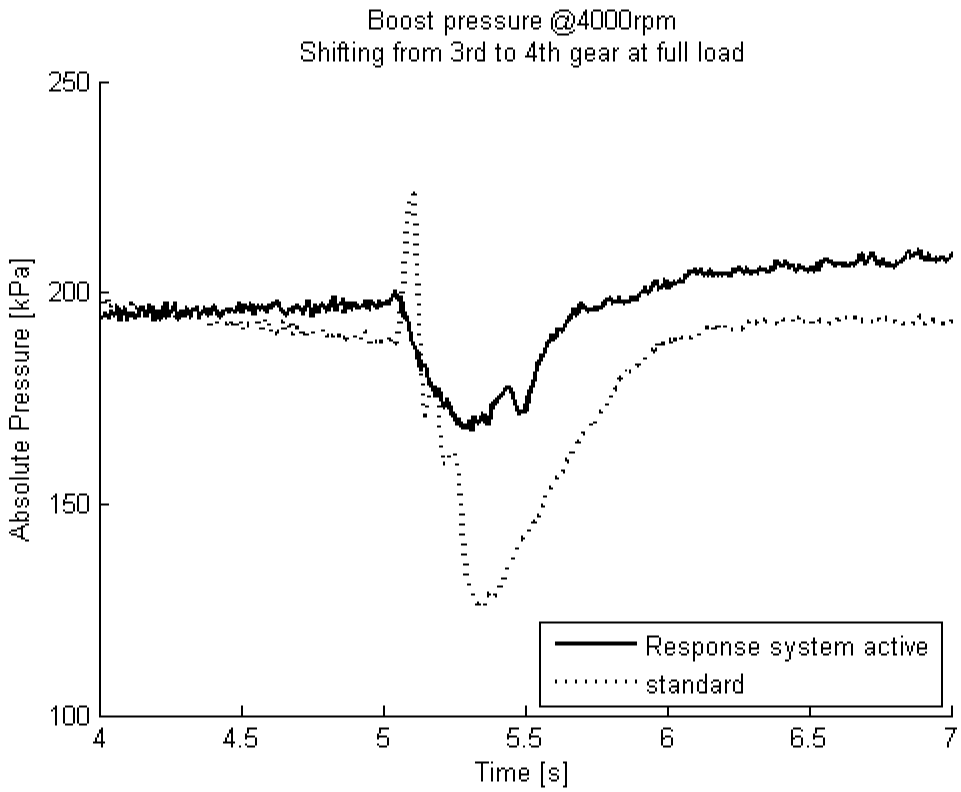

Figure 27 Full load gear change from 4000rpm in 3rd to 4th gear with and without response system active

In the run above the clutch is pressed five seconds into the measurement and fully released after 5.4 seconds have passed. The effect the system has on exhaust gas temperatures is barely noticeable. The engine is run at heavy load, with high exhaust temperatures, before the function is triggered, and the time it is active is limited.

6.3 Launch control

In this chapter the results from the launch control testing is presented. The focus has been on manual transmission but tests have also been conducted with a vehicle with automatic transmission and all wheel drive.

6.3.1 Manual transmission

The test results in this section come from a test session at Volvo and they were conducted during a warm and sunny day on a asphalt track. Daniel Magnusson was the driver and since he works with these kinds of tests on a daily basis the procedure before and during each take off is comparable. The fact that Daniel is an experienced driver results in a good comparison on how well the launch control performs. During the acceleration tests the gear shift mechanism was failing and fast gear shifts from first to second gear were difficult to perform. Therefore the comparison is limited to the first gear. This section is good to look at when comparing the launch control with regular driver dependant take off. The need to control front wheel slip is most crucial in the beginning of the acceleration.

The idea with the launch control system is to make it easier for the driver to get repeatable fast starts with a controlled front wheel slip during the acceleration phase. In Figure 28 a comparison between take offs with and without the launch control activated are shown. The figure shows vehicle acceleration in first gear from zero to three seconds, which represents approximately 50 km/h. The top and bottom measurement represents inactive launch control and active launch control respectively. The launch control is set to maintain the front wheel slip at 12 percent.

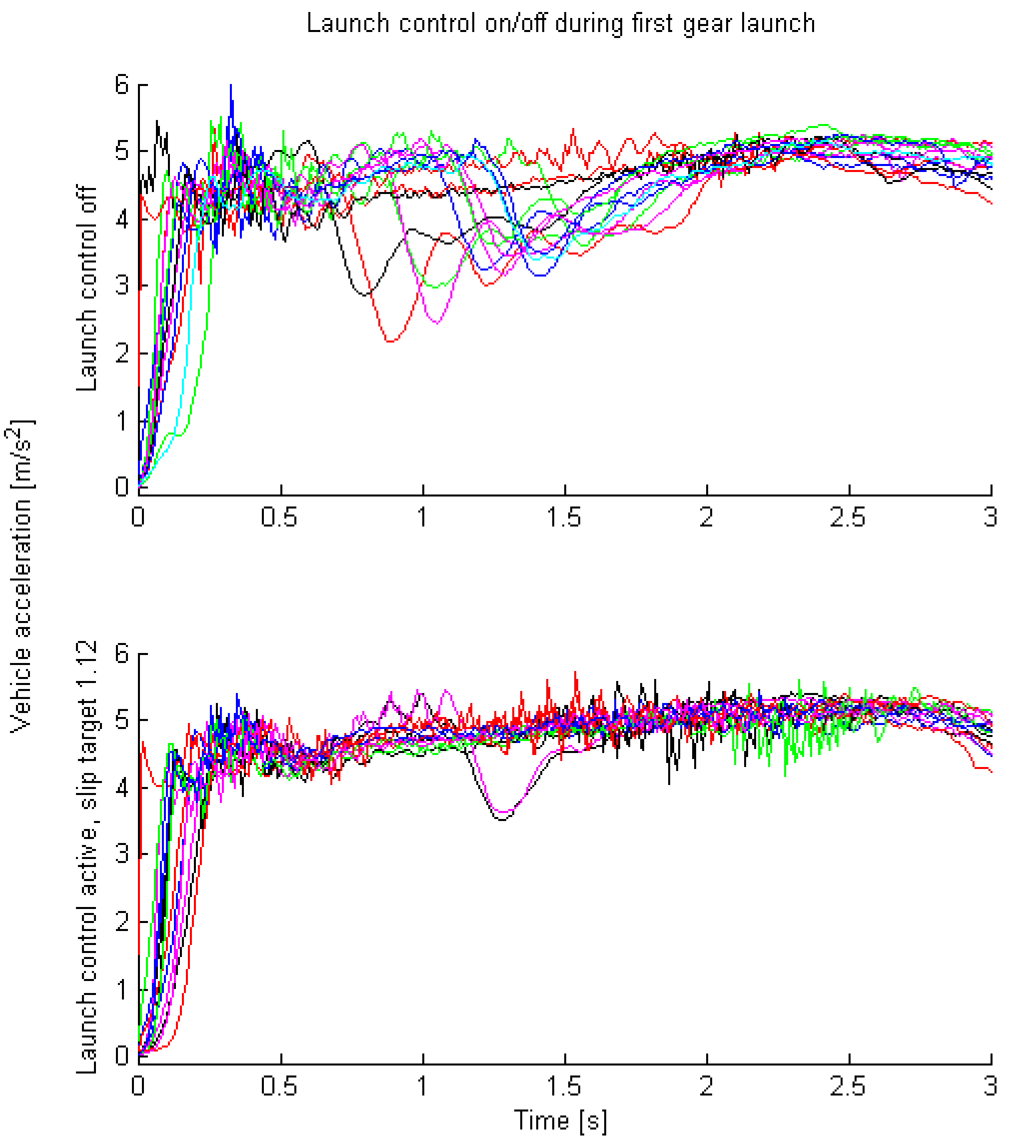

Figure 28 Launch with and with out launch control.

Figure 28 also shows that the acceleration level fluctuates and varies between the different measurements when the launch control is not activated. When the launch control is activated the acceleration level is more stable, less fluctuation, and in the same region during the span of the measurement.

In both cases the vehicle acceleration peak is at the same level but when the driver manually controls the wheel slip a greater variation is observed between runs. When the launch control is activated the acceleration is maintained at an almost constant level throughout the entire launch situation, and variation between runs is minimal. This result shows that the system is helping the driver.

In Table 1 the acceleration times from the same tests as seen in Figure 28 are stated. The time difference between using or not using the launch control is small, but with the launch control active the take offs are repeatable and fast, nine results below three seconds compared to one result below three without launch control.

Table 1 Acceleration times 0-50 km/h

Acceleration 0-50	
NoLC	LC12
2.9500	2.9000
3.0100	2.9100
3.0400	2.9100
3.0400	2.9200
3.0800	2.9200
3.1000	2.9500
3.1100	2.9600
3.1200	2.9600
3.1300	2.9700
3.1500	3.0000
3.1600	3.0000
3.1700	3.0100
3.1900	3.0100
3.2200	3.0800
3.2900	3.1600

In Table 2 acceleration times 0 to 50 km/h are seen. NoLC, LC08, LC12, LC15, and LC20 represents no launch control active, launch control with 8, 12, 15 and 20 percent front wheel slip respectively. 12 percent slip generated the fastest repeatable times in this acceleration test, this is as seen in Figure 7 slightly before the peak in tire mu-slip behavior at 15 percent. An explanation to this could be that when 15 percent slip or higher is the target the wheels start to hop, so called wheel-hop. This should be avoided since it can cause damage to the driveline components.

Table 2 Comparing zero to 50 km/h accelerations with different launch control settings

Acceleration 0-50 km/h				
NoLC	LC08	LC12	LC15	LC20
2.9500	2.9700	2.9000	2.9200	2.9500
3.0100	2.9700	2.9100	2.9300	2.9700
3.0400	2.9900	2.9100	2.9400	2.9800
3.0400	2.9900	2.9200	2.9400	3.0100
3.0800	3.0000	2.9200	3.0800	3.0100

To further compare the launch control with an ordinary driver regulated launch the results in Figure 29 are interesting. In the figure front wheel speed and vehicle speed are compared for different starting procedures. Three driver controlled launches and one with the launch control activated. The three driver controlled launches are: one with to much wheel spin (overspin), one where the vehicle "bog's"(to low engine speed when releasing the clutch) and one successful fast launch. The data is filtered to reduce the largest fluctuations for clarity. When looking in the figure comparing the four cases it is seen that a fast driver controlled launch is close to a launch with the launch control active. A good driver can regulate the wheel slip and maintain it at a proper level through out the acceleration. However it is more common for regular drivers to either get to much wheel spin or too little. It is in these cases the launch controls works best, making an inexperienced driver perform launches like an expert.

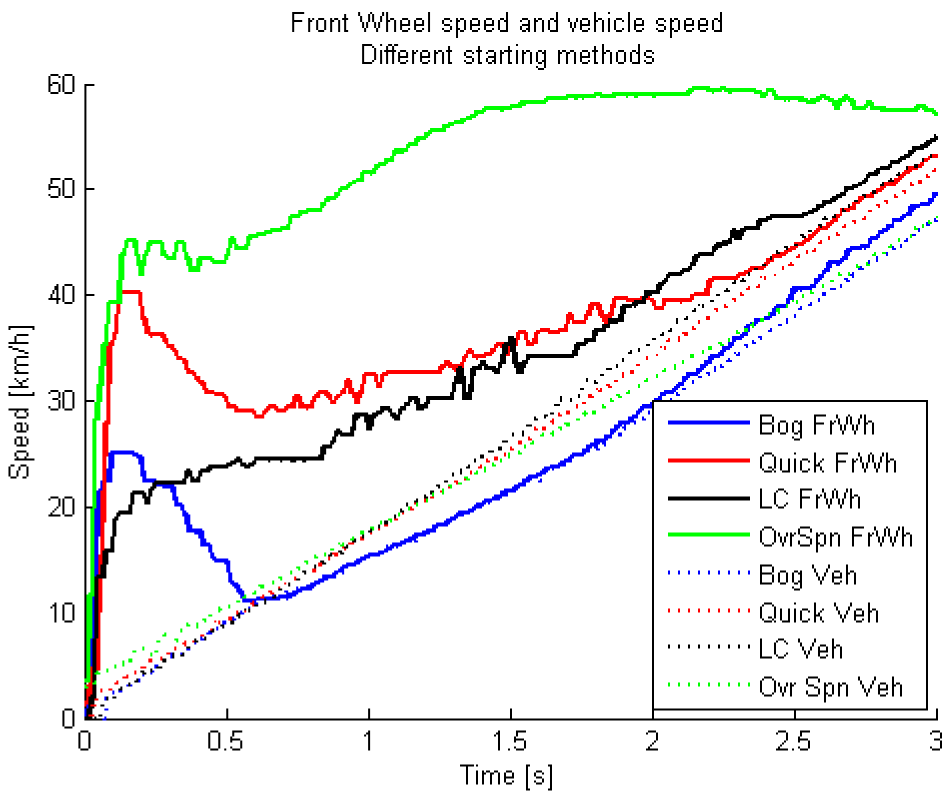

Figure 29 Front wheel and vehicle speed for different start methods

6.3.2 Automatic transmission

An S60 T6 AWD with automatic transmission can improve 0-100km/h time with 0.2 seconds by adding a torque reserve of 100Nm when stalling the gearbox before take off. A comparison can be seen in Figure 30. The peak acceleration is also 18% higher in this case. Further improvements can theoretically be achieved with even more torque reserve but it has not been tested. Injection cuts could be used to get similar results but with less stress on the components.

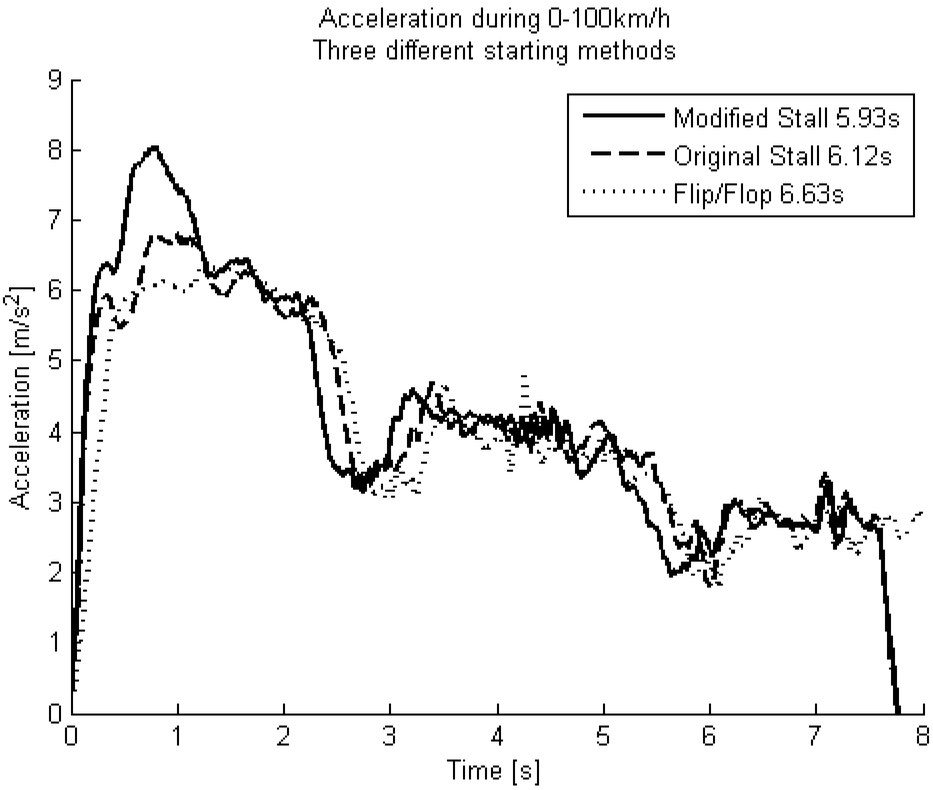

Figure 30 Acceleration 0-100km/h with three different starting methods

6.4 Down shift support with manual transmission

The down shift support resulted in a smoother ride. When shifting down the engine speed is increased to match the engine speed to that of the gearbox and the engagement of the clutch passes unnoticed. A run with down shifts from 6^{th} to 2^{nd} gear can be seen in Figure 31. The triggering functionality feels natural in most cases but sometimes results in unwanted aid, for example when pulling in towards a red light and disengaging the gear to stop, the engine revs up. For it to feel as sporty as desired the acceleration to the target speed needs to be improved.

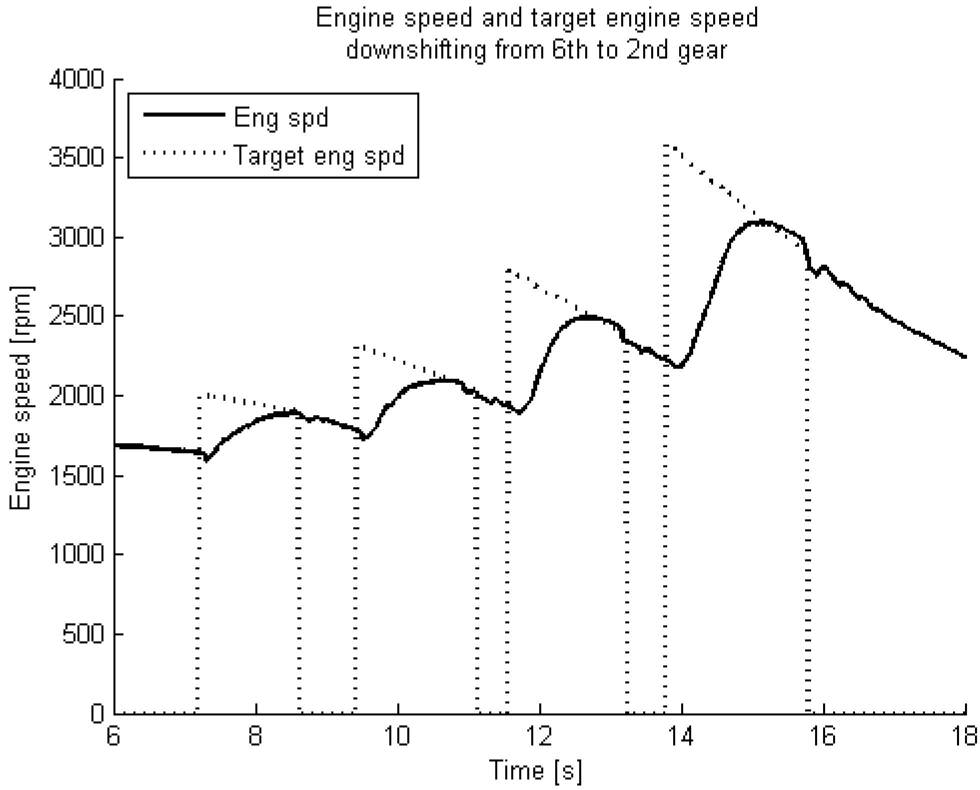

Figure 31 Downshifting with downshift support activated

When having the brake pedal pressed and pressing the clutch a target engine speed is activated. It then takes the engine about 1.5 seconds to reach the target speed, which is slow but no further calibration was made to try and improve this. Once the target speed is reached the clutch pedal can be let off abruptly without any noticeable jerk.

6.5 Controlled exhaust detonations

The functionality to create exhaust detonations work and it is possible to decide how many and how loud the bangs should be. It is noticed that a lot of factors play an important role in the resulting detonation. For instance the bangs when detonating after running the engine at high load is louder than when running the engine at medium or low load. It depends on the amount of fuel and air charged into the exhaust. The exact amount of fuel and air are factors not accounted for in the control strategy which only focuses on the ignition system. This results in that the driver feels that he has the possibility to affect the outcome of the detonation which is perceived as positive.

When asking for more than three detonations in a row reliability is lost. Since the fuel injected is reduced during the transient when the engine speed is decreasing, the fuel and air mixture charged into the exhaust becomes less the more time that passes. This means that the more detonations pass the quieter they become. After three to four detonations in a fast sequence have passed there simply is not enough unburned mixture to ignite.

The impact the detonations have on the driver and passengers in the car is very positive and it is almost impossible not to smile. The result is a car that feels like it wants to be driven hard since it rewards the driver and passengers with a louder bang.

6.6 Skip stroke

The skip stroke functionality was originally intended purely for the sound experience. The sound when engaging it is special but not as thrilling as desired, but it could be used to indicate that something special is going on. When running with a higher cut interval than every third injection vibrations start to become uncomfortable and the feel is more of that something is wrong rather than sporty or exciting.

The skip stroke functionality has however proved to have other qualities; it can be used to build torque reserves, as can be seen in Figure 32, with relatively cool exhaust gasses, shown in Figure 33 since there is fresh air pumped through the cylinders every time there is a missing injection. This air mixes with the exhaust gasses and cools them down.

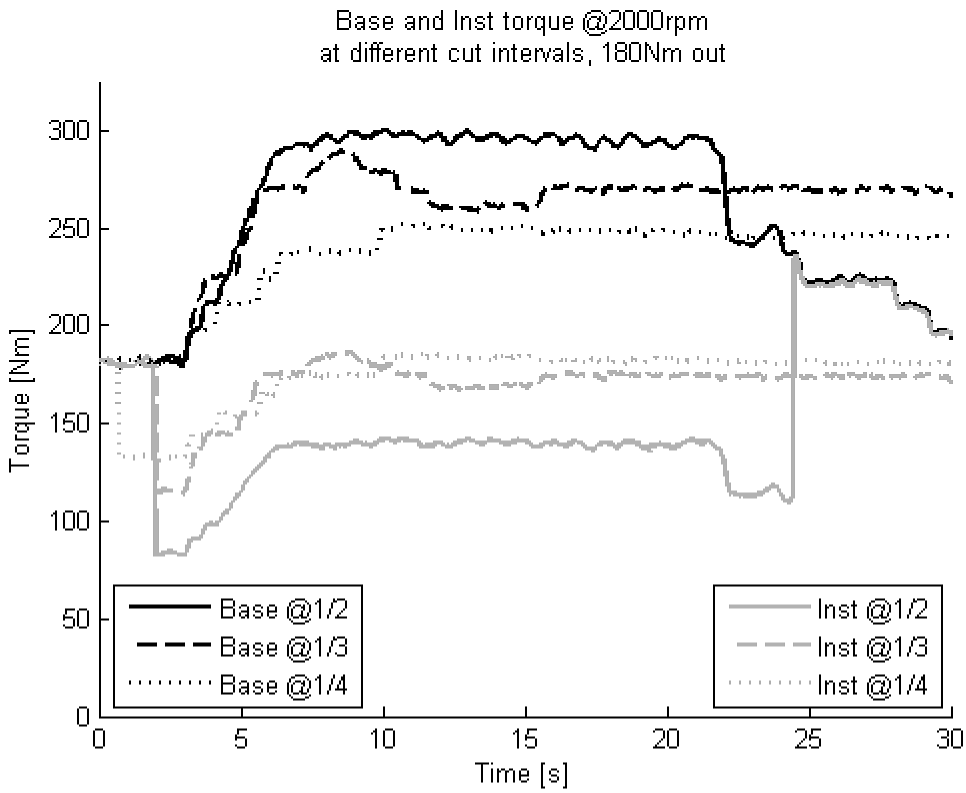

Figure 32 Running at 180Nm load without and with skip stroke

As seen above cutting every other injection results in a crankshaft torque that is one half of what would normally be produced. This means that with a base torque of 300Nm the instantaneous torque or torque out is 150Nm. 150Nm is about maximum that was possible to reach when cutting every other injection. Cutting one in three means that one third of the requested torque is lost, or turned in to torque reserve. This method of building torque reserve could be used when stalling the gearbox in an automatic transmission vehicle. For this situation cutting every third injection is suitable. This should result in a noticeably better acceleration time, compare to the run in 6.3.1, but this method would result in lower exhaust and turbine temperatures. The use of skip stroke in an automatic transmission stall has however not been tested in car.

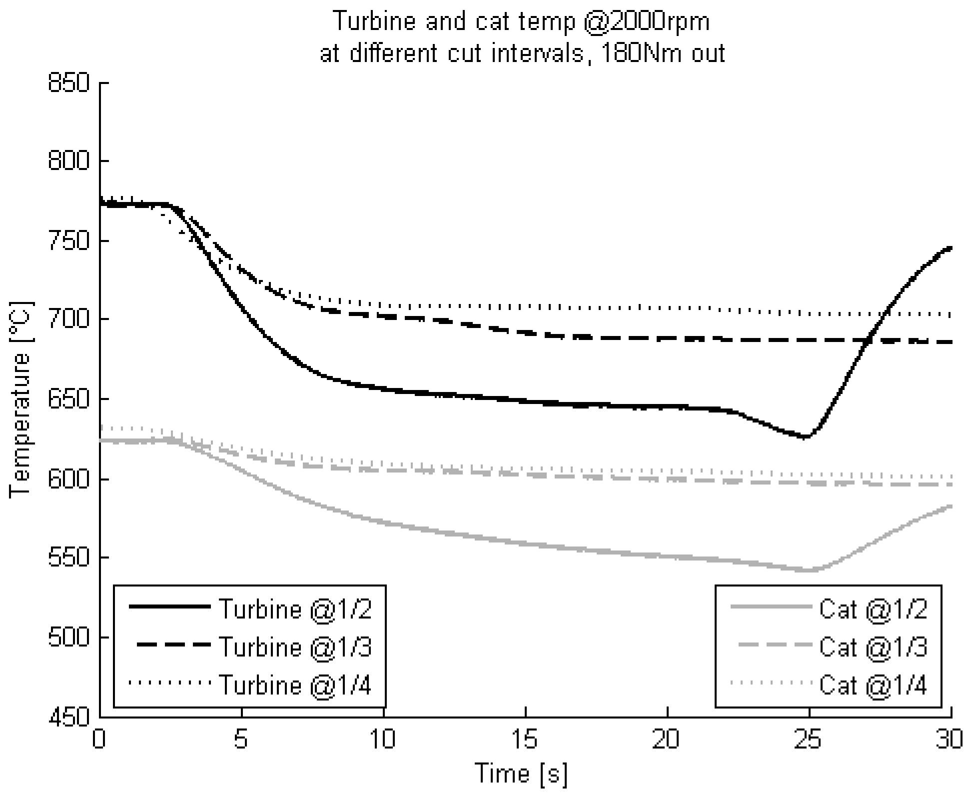

Figure 33 Turbine and catalyst temperatures while running skip stroke

Figure 33 shows that the temperatures of the turbine and the catalyst are decreasing. The more often a stroke is skipped the more fresh air is introduced into the exhaust and thus a lower temperature is obtained.

Another advantage with using the skip stroke functionality to create a torque reserve is that the fuel consumption is barely affected. Since the same power output is desired but the engine is running on fewer cylinders the same amount of fuel is required to burn in order to produce the specific amount of energy. When using the method of retarding the spark to get a torque reserve more fuel is burned at a lower efficiency.

6.7 Throttle response in neutral

The feel of the accelerator pedal is much more distinct and direct with the new pedal map than with the standard configuration. The most noticeable difference is that the engine speed goes up to a certain level and then stays stable at that point in contrast to the standard configuration where a fixed accelerator pedal position results in a slowly but steadily rising engine speed. This can be seen in Figure 34. About 30 seconds into the measurement the pedal is held steady but the engine speed keeps climbing. With the modified pedal map the pedal position is in direct relation to the engine speed. This can be seen when increasing the pedal position in steps and the engine speed acts accordingly.

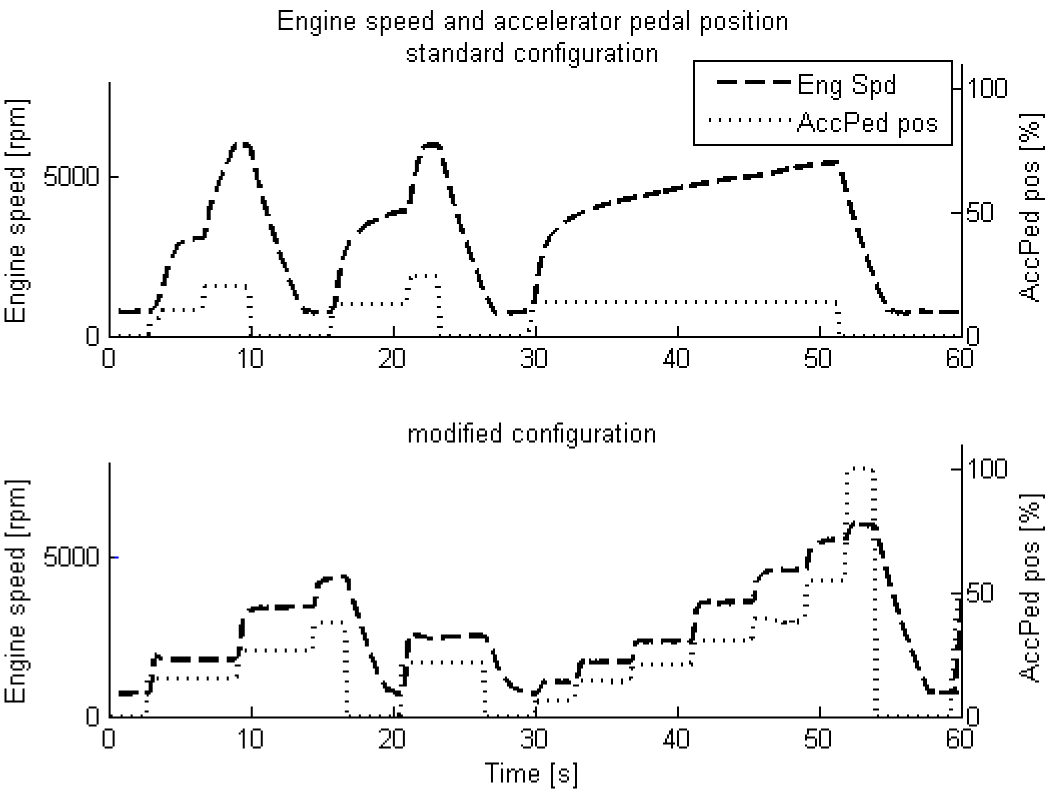

Figure 34 Comparison of engine response with standard and modified pedal maps

The feeling of the difference is hard to communicate via text and graphs and should be experienced in person in order to be fully comprehended.

7 Conclusions and discussions

The conclusions chapter is divided in to subchapters for each feature and a final section for general conclusions.

7.1 Torque reserve

It has been proved that torque reserves are possible to create in a variety of situations. In the no load case the possibility to create torque reserves is limited by the high rate of temperature increase in the exhaust. The engine also proved to be able to operate satisfactory at spark timings far more retarded than expected.

The possibility to create substantial torque reserves has been important for the development of the other features and is present as part of the response system during up-shifts, during take off with both manual and automatic transmission and during regulation of wheel speed in the launch control feature

The gain of operating the engine with a torque reserve is the response aspect since the output is possible to control with spark and fuel and therefore can be adjusted in between two consecutive combustions. The drawback is that the engine is operated with a low efficiency since a lot of energy is transformed to heat without getting any work out on the crankshaft. This results in high thermal stress on exhaust components and high fuel consumption during this mode of operation.

7.2 Response system during up shifts

The response system prevents the boost pressure to drop below 160kPa absolute pressure during the course of an up shift. 160kPa seemed to be the maximum that was possible to produce with the current engine set up. The use of a larger turbocharger would most likely result in a more noticeable turbo lag and in that case an application like this would be even more useful.

Since the functionality is only active during the course of a gear change, the increased fuel consumption will be barely noticeable. Assuming the response system is active throughout the shift results in a gain in fuel consumption of about 2ml per shift, which can be accepted during active driving. The driver also has the possibility to choose whether or not to use it by keeping the accelerator pedal pushed through the shift or releasing it to get a normal shift.

Since it only is active for such a short period in time it was concluded that it should not cause any excessive wear on the catalytic converter.

The sound of the response system also indicated that something special is going on and the nature of it gives a powerful impression.

7.3 Launch control

The launch control can be concluded to help any driver become a professional drag racer. The acceleration times using launch control matches those times of the professional test driver VCC supplied and the results are possible to reproduce every time, providing the gear shifts are executed accordingly. The electronically controlled clutch is most likely the reason to why these kinds of systems are more common on vehicles with dual clutch. The drawback with the current setup is that every driver handles the clutch differently and this has to be taken into consideration in order to limit the clutch wear and maintain the specified lifetime of the clutch components.

It can also be concluded from tests on high friction surface that the launch control would be of even more help if the engine was able to produce more power. With the current vehicle setup the engine only manages to achieve the target slip rate throughout half of first gear on asphalt. If more power was available the launch control could be active for a longer time and the improvement compared to not having such an option would be even more obvious.

It should also be noted that some wheel hop becomes apparent during the launch process. This phenomenon induces wear on the driveline and suspension components and should be avoided but it was not possible to look any further into this within the timeframe of the project.

The mu estimation functionality was not finished so this was not possible to test. Instead a mu value was put in manually. The controller is however capable of accounting for rather large faults in the estimation of surface friction.

7.4 Down shift support with manual transmission

The down shift support results in a smother and more enjoyable drive. The aid is also very obvious and hence the driver is urged to use it during normal driving as well. The feeling is not as sporty as intended due to the characteristics of the engine and its inability to increase in speed fast. It can however be concluded that in a situation when entering a corner with speed the driver can focus on driving and the car aids in getting the smoothest of downshifts, keeping the vehicle stable and easy to control.

7.5 Controlled exhaust detonations

The exhaust detonation functionality can be concluded to bring out the playfulness in people. It is very common among the test drivers to get an urge to try to get a detonation again, and since it is rather well controlled it will occur on every instance at load. As the triggering conditions were set at the end of the project it was almost to easy to get an exhaust detonation, which resulted in that it gets tiresome, a condition to only induce detonations at high load should be introduced in order for the functionality to feel more natural, currently the detonations can feel a bit artificial.

In order to fully control the exhaust detonations it is important to:

- Have a good base engine calibration.
- Have control over the air/fuel ratio in the exhaust.
- Have continuous combustions when the engine is decelerating. No injection cut or misfires are allowed.

- Knowing the current engine load since it influences the outcome of the detonation.
- Be able to control the ignition and retardation for each cylinder separately and accurately.

A big drawback of this feature is that it introduces unburned fuel into the exhaust and ignites it in the catalyst which is negative for the lifetime of the catalytic elements. No real analysis on the effect of this has been conducted within this project.

7.6 Skip stroke

The sound of the skip stroke functionality can be concluded to be different and clearly indicates that something is going on. Since it involves cutting the injection to cylinders, care has to be taken in order not to chose an interval that results in awkward vibrations or a sound of malfunction, as for instance when cutting every fifth cylinder which results in the engine sounding as if it does not run on all cylinders.

It can also be concluded that the ability to create a torque reserve using injection cuts can be an alternative to creating the torque reserve by simply retarding the spark angel and controlling amount of fuel injected. Since it results in the exhaust temperatures dropping it is the preferred alternative where a reserve is needed for a period longer than just a few seconds. Fuel consumption is not affected either.

The fact that a lot of fresh air is pumped into the exhaust will degrade the catalytic converters NO_x conversion efficiency, which may cause problems with emissions.

7.7 Throttle response in neutral

The addition of an alternative pedal map for neutral engine operation can be considered important since it affects how the driver to car communication is perceived. This is an important matter in order for the driver to feel confident with his vehicle and should not be underestimated.

The feel with the new pedal map can be concluded to induce a feeling of distinctiveness and direct contact with the engine.

7.8 General

The complete package of all the developed features result in a car that is a lot more tempting to drive and it begs to be played with. The feel is more oriented towards a sporty and enthusiastic driver. Had the test vehicle been of a sportier nature to start out with, the results are believed to be even more noticeable. An S80 does not ask to be driven hard; these kinds of features would be better suited in a smaller car with a higher grade of engine tuning, like an R model of an S60 or a Polestar version of the C30.

8 Future work

In this section a list of suggestions for what need to be further investigated in order to reach a production level status is presented.

8.1 Torque reserve

- The effect large torque reserves have on turbocharger and catalytic converter in the aspect of excessive heat and combustion in the exhaust needs to be analyzed and documented.
- The effects on emissions need to be analyzed and documented.
- Investigate how far the spark angle can be retarded for different running conditions without misfire or excessive exhaust gas temperatures.
- Analyze and find a maximum time for how long a torque reserve can be held before to high temperatures are reached
- Have a temperature dependent triggering condition or limiter in case high temperatures are reached.
- Find the maximum torque reserve possible during load in regards to misfire and find the cause of the misfiring.

8.2 Response system during up shifts

- The effects on emissions need to be analyzed and documented.
- Have a temperature dependent triggering condition or limiter in case too high temperatures are reached.

8.3 Launch control

- Further develop the surface friction estimation functionality.
- Add protection against wheel hop.
- Look in to driver aid oriented uses, for instance to help prevent stall when starting with a heavily loaded vehicle in an uphill slope.
- Look further into optimizing controller parameters.
- The clutch release dependency can be further improved.
- Look in to electronically controlling the clutch.
- Add possibility for the driver to manually set the take off engine speed.

- Investigate how it cooperates with traction control by brake. Especially on split-mu.

8.4 Down shift support with manual transmission

- Further develop triggering conditions in order to avoid triggering in inappropriate situations.

- Investigate ways of improving engine acceleration.

- Consider the safety aspect of the functionality since it involves an increase in torque demand without the driver putting his foot on the pedal.

8.5 Controlled exhaust detonations

- Add a load dependent triggering condition.

- The effect exhaust detonations have on turbocharger and catalytic converter needs to be analyzed and documented.

- The effects on emissions need to be analyzed and documented.

- The effect the sudden pressure increase in the exhaust has on components such as exhaust valves and exhaust system.

- Further testing needs to be conducted in order to get rid of the artificial feeling.

8.6 Skip stroke

- The effect torque reserve using skip stroke has on turbocharger and catalytic converter needs to be analyzed and documented

- The effect on emissions need to be analyzed and documented

- Further testing of running scenarios in this mode, for instance could the engine been run with every third stroke skipped in order to always have a torque reserve ready.

- Test other intervals of injection cut; to skip more than one stroke in a row and analyze the effect it has on driver impression, power output and ability to create torque reserves.

- Investigate influence of fuel enrichment compensation and target lambda functionalities.

8.7 Throttle response in neutral

- Proper triggering conditions need to be set up. The current version requires manual switching of maps.

- The transition between throttle maps needs to be accounted for.

8.8 General

- For all features dependability issues need to be found, documented, discussed and handled.

- Triggering conditions need to be thoroughly tested and analyzed in order to avoid triggering a function at the wrong time or triggering two conflicting functions simultaneously.

- The additional enthusiast features listed in Appendix A should be prototyped and tested.

- When testing the response system it was found it could be used during steady state driving by slightly pressing the clutch to activate it without disengaging drive, then flooring the accelerator pedal to build boost and when releasing the clutch pedal that reserve is realized instantly resulting in a kick in acceleration. It needs to be further investigated if some sort of driver requested torque reserve build up could be implemented as a separate enthusiast feature.

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APPENDIX

APPENDIX A

Adjustable shift quality AT

Adjusting the gear change in an AT between firm and soft depending on the driver needs. This demands different settings on the gearbox control module which is delivered from the manufacturer. Therefore this feature makes it necessary to buy a new control strategy.

Torque buildup during turbo transients

(Torque build up controlled by drivability functions during turbo transients) The torque build up today is a smooth and flat curve which can make the engine be perceived as boring. If the torque curve is controlled to give a sudden increase the vehicle will be perceived as faster. One problem here is that the vehicle can become slower because of the removal of torque at lower engine speeds. This can be realized either by retarding the ignition or lowering the boost pressure at lower engine speeds.

Manual clutch with mechatronics to support take off

An electronically controlled clutch mechanism makes it possible to always have the right release rate. This will make it easier to control take off since a manual clutch is hard to release with the same consistency by a driver.

Shift cut / flat shift

This is a feature that is used to remove the torque output from the engine during gear change. This can make the gear change quicker and smoother since there is no torque in the gearbox. It will also let the driver keep the throttle pedal down decreasing the maneuvers the driver has to make during shifting while also maintaining a steady gas flow through the engine. A big problem with cutting the ignition is that the catalyst will most likely melt, if the fuel is not cut at the same time.

AT ”programmable” downshifts

When entering a corner and already knowing what gear to use it should only be needed to blip the tiptronic or the paddles (if such exist) as many times as the amount of gears desired to shift down. If in 5th gear and entering a corner wanting to use the 2nd gear, blip 3 times at the paddle and then the gearbox controller controls the downshifts to occur at the right moments.

Take off enhancement when leaving brake pedal by dynamic torque reserve, AT

When leaving the brake pedal there is a delay time depending on the pressure in the converter. This feature is to increase the engine speed hence the pump speed and start to build up pressure when the driver leaves the brake pedal. It is important to know what the driver is doing so that this does not come as a surprise if a quick take off is not wanted.

Engine speed control at normal take off in AT vehicle

Today the torque out to the wheels is demanded from the engine. However in standstill and up to a certain speed the converter in the automatic transmission increases the torque out to the wheels which makes it useful with a function that compensates for the torque increase and sets the engine torque so that the proper torque on the wheels is received.

Pedal interpretation that does NOT saturate at 100% torque request

This is not so much a feature for the end customer as it could be a tool for engine control and the interpretation of what the driver wants. On current pedal maps the torque request saturates at 100 percent. The way some cars are configured today give 100 percent saturation at sometimes as low as 20 percent of the available pedal travel. This means that the engine control unit cannot tell the difference between 20 percent and full throttle. Since the engine cannot deliver more than 100 percent of the available torque a pedal interpretation that does not saturate at 100 percent will give no performance gain, it can however give an important clue as to how the driver wants the vehicle to behave and it could be used as a trigger to toggle some enthusiast features, such as a valve connecting the intake to the firewall in order to get a more thrilling engine sound in the passenger compartment during full throttle accelerations.

Adjustable electronic driving support level

Allow the driver to manually adjust parameters influencing the vehicle characteristics such as adjustable pedal map settings, GSH settings, M/T take off settings, gear shift indication, ESC settings etc.

ESC drift control mode

For drivers that sometimes push their car to the limit it can be very annoying if the ESC system comes in to early or to hard. It can sometimes be seen as a distraction or a discrepancy when it cuts in since it is very difficult to predict when it will turn on. Therefore it would be of interest for such enthusiastic drivers to be able to let the ESP system allow for a larger yaw angle, or drift angle, before intervening with the actions of the driver. The car will feel sportier and more dynamic if it is not obvious that it is holding the driver back.

Enhanced engine sound during acceleration

Modern cars are very focused on comfort and sound insulation is a high priority. This results in a quiet and comfortable drive but sometimes the owners may want their car to give off more sound in order for it to communicate clearer to the driver and thrill the people around. The alternative is to mount some kind of aftermarket exhaust system or muffler that is noisier, but then the comfort is lost during all driving scenarios. To get the car to sound sporty when that is desired and to be comfortable and quiet when that is desired controlled valves could be used. Some cars have a sound symposer, a membrane that transfers intake sound from the engine into the passenger compartment. This valve is opened during heavy acceleration in order to communicate the engine sound to the driver in a louder fashion, resulting in a car that feels more responsive since it obviously is louder during heavy acceleration. Another solution is to mount a valve in the tailpipe (providing there is more than one). When the valve opens the exhaust flows more freely which also could be positive when the engine is operating at high revolutions and pumps out large volumes of exhaust gasses. This makes the car not only louder to the driver but to everyone around the car as well.

Brake shift, gear hold

Brake shift, when in sport mode using an AT it is a demand for different gear change strategies. During braking it is preferred that the gearbox shifts to a lower gear earlier so that the engine speed is kept high, or around the peak power point.

Gear hold, driving in a long "steady state" corner it is wanted to use the same gear all the way around the corner. Today the gearbox changes to a higher gear which reduces the corner –exit speed since it is necessary to change down a gear to reach peak power.

APPENDIX B

Table B1 Powertrain inertia

Powertrain inertia	
Component	J [kgm^2]
Eng, aux	CONFIDENTIAL VALUES
Flywheel primary	
Flywheel secondary	
Clutch	
Front wheel axle	
Gear R	
Gear 1	
Gear 2	
Gear 3	
Gear 4	
Gear 5	
Gear 6	