MASTER

Documentation of the control software in the VW Bora

Martin, G.Y.

Award date:
2004

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Documentation of the control software in the VW Bora

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Eindhoven, 30 July 2002
Preface

In the EcoDrive Project software is written in Matlab-Simulink to control the Zero Inertia powertrain [Vroemen, Serrarens, van Druten 2001]. The idea of this paper is to understand the control software hierarchy and to understand the mechanisms within the Zero Inertia vehicle. For further development of the Zero Inertia powertrain a properly documented control scheme is vital and forms the contents of this report.

In this documentation first the layout of the vehicle is given. After that the complete control scheme is given. Then a short description of the blocks is given and in the next paragraphs and chapters every block is decomposed into smaller parts. By decomposing the blocks it will be seen what assumptions had to be made and also which components (e.g. sensors) and calibrations are used.

The last part of the report contains the Simulink schemes to understand how the Zero Inertia powertrain operates.
Contents

Preface ................................................................................................................................. 2
Symbols ................................................................................................................................. 5

Chapter 1 Control scheme of the software ........................................................................... 7
  1.1 Overview of the VW Bora ......................................................................................... 7
  1.2 Main blocks ............................................................................................................... 8
  1.3 Signals Calibration & Filtering Block ...................................................................... 9
    1.3.1 MUX_ADC ........................................................................................................... 9
    1.3.2 MUX_CH ........................................................................................................... 11
    1.3.3 MUX_I/O .......................................................................................................... 12
    1.3.4 MANUAL .......................................................................................................... 12
  1.4 Diagnostics & Demux Block ................................................................................... 13
  1.5 Monitors .................................................................................................................... 13
  1.6 Safety Controls ........................................................................................................ 14
  1.7 Signals Out ................................................................................................................ 14

Chapter 2 Coordinated Control .......................................................................................... 15
  2.1 Schematic overview and function .......................................................................... 15
  2.2 Driver ....................................................................................................................... 15
  2.3 Drive Pedal Translation ......................................................................................... 15
  2.4 CVT Ratio Setpoint ............................................................................................... 15
  2.5 ICE Torque Setpoint .............................................................................................. 16
  2.6 TqC Lock-Up Setpoint ........................................................................................... 16

Chapter 3 Component Controllers ....................................................................................... 17
  3.1 Inputs & outputs Component Controllers ............................................................ 17
  3.2 Throttle E-motor control ....................................................................................... 17
  3.3 ZI Transmission ...................................................................................................... 17
    3.3.1 Pump mode ....................................................................................................... 17
    3.3.2 Variator Control ............................................................................................... 18
    3.3.3 Torque converter PWM Lock-up steering ....................................................... 18
    3.3.4 Drive Clutch control ....................................................................................... 18

Appendix 1 References ........................................................................................................ 18
Appendix 2 Sensors & Calibration functions of the analogue sensors .................................. 20
Appendix 3 “Signals Calibration & Filtering” .................................................................... 22
Appendix 4 “Signals Calibration & Filtering \ Analogue Sensors” ........................................ 23
Appendix 5 “Signals Calibration & Filtering \ Channels” ..................................................... 24
Appendix 6 Cockpit (dSPACE) module ............................................................................ 25
Appendix 7 “Signals Calibration & Filtering \ Inputs from Cockpit” ................................. 26
Appendix 8 “Diagnosis & Demux \ Diagnosis for Coordinated Control” ......................... 27
Appendix 9 “Diagnosis & Demux \ Diagnosis for Safety Controls” ............................... 28
Appendix 10 “Diagnosis & Demux \ Diagnosis for monitor signals” ............................... 29
Appendix 11 “Diagnosis & Demux \ Diagnosis for component controllers” .................... 30
Appendix 12 “Monitors” .................................................................................................. 31
Appendix 13 “Safety Controls” ...................................................................................... 32
Appendix 14 “Safety Controls \ Signals out” ..................................................................... 33
Appendix 15 “Coordinated Control” ............................................................................... 34
Appendix 16 “Coordinated Control \ Driver” .................................................................... 35
Appendix 17 “Coordinated Control \ Driver \ PI driver” ..................................................... 36
## Symbols

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEANING</th>
<th>UNITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ang_dp</td>
<td>angle of the drive pedal</td>
<td>[°]</td>
</tr>
<tr>
<td>ang_tv</td>
<td>angle of the throttle valve</td>
<td>[°]</td>
</tr>
<tr>
<td>ang_tv_des</td>
<td>desired angle of the throttle valve</td>
<td>[°]</td>
</tr>
<tr>
<td>a_radf</td>
<td>radial flywheel acceleration</td>
<td>[m/s²]</td>
</tr>
<tr>
<td>a_veh</td>
<td>vehicle acceleration</td>
<td>[m/s²]</td>
</tr>
<tr>
<td>brake pedal trigger</td>
<td>to see if brake pedal is pressed or not</td>
<td></td>
</tr>
<tr>
<td>distance</td>
<td>distance covered by vehicle</td>
<td>[m]</td>
</tr>
<tr>
<td>dot i</td>
<td>derivative of i</td>
<td>[1/s]</td>
</tr>
<tr>
<td>dot_i_des</td>
<td>derivative of i_d</td>
<td>[1/s]</td>
</tr>
<tr>
<td>DNR_D</td>
<td>drive of the DNR set</td>
<td>-</td>
</tr>
<tr>
<td>DNR_N</td>
<td>neutral of the DNR set</td>
<td>-</td>
</tr>
<tr>
<td>DNR_R</td>
<td>reverse of the DNR set</td>
<td>-</td>
</tr>
<tr>
<td>dot N_e</td>
<td>derivative of N_e</td>
<td>[rpm/s]</td>
</tr>
<tr>
<td>dot N_p</td>
<td>derivative of N_p</td>
<td>[rpm/s]</td>
</tr>
<tr>
<td>dot N_s</td>
<td>derivative of N_s</td>
<td>[rpm/s]</td>
</tr>
<tr>
<td>drive</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>em. button</td>
<td>signal that detects if emergency button is pushed</td>
<td>-</td>
</tr>
<tr>
<td>fcn</td>
<td>a function in Simulink</td>
<td>-</td>
</tr>
<tr>
<td>foot pedals</td>
<td>checks to see if a signal from the pedals is needed</td>
<td>-</td>
</tr>
<tr>
<td>foot tracking</td>
<td>the angle of the drive pedal determines the angle of the throttle opening</td>
<td>-</td>
</tr>
<tr>
<td>i</td>
<td>ratio</td>
<td>[s]</td>
</tr>
<tr>
<td>i_des</td>
<td>desired ratio</td>
<td>[s]</td>
</tr>
<tr>
<td>i_r</td>
<td>realized ratio (in most cases equal to i)</td>
<td>[s]</td>
</tr>
<tr>
<td>LU</td>
<td>lock up</td>
<td>-</td>
</tr>
<tr>
<td>MUX_ADC</td>
<td>MUX analogue to digital converter</td>
<td>-</td>
</tr>
<tr>
<td>MUX_BIT</td>
<td>on/of signals (same as MUX I/O, but output)</td>
<td>-</td>
</tr>
<tr>
<td>MUX_CH</td>
<td>MUX channels</td>
<td>-</td>
</tr>
<tr>
<td>MUX_I/O</td>
<td>in/out channels, in this case only in</td>
<td>-</td>
</tr>
<tr>
<td>N_e</td>
<td>engine speed</td>
<td>[rpm]</td>
</tr>
<tr>
<td>N_p</td>
<td>speed of the primary pulley</td>
<td>[rpm]</td>
</tr>
<tr>
<td>N_f</td>
<td>flywheel speed</td>
<td>[rpm]</td>
</tr>
<tr>
<td>N_p_min</td>
<td>minimal primary pulley speed</td>
<td>[rpm]</td>
</tr>
<tr>
<td>N_s</td>
<td>speed of the secondary pulley</td>
<td>[rpm]</td>
</tr>
<tr>
<td>N_t</td>
<td>turbine speed</td>
<td>[rpm]</td>
</tr>
<tr>
<td>N_wheel_r</td>
<td>rear wheel speed</td>
<td>[rpm]</td>
</tr>
<tr>
<td>O/C</td>
<td>open or closed (lock up)</td>
<td>-</td>
</tr>
<tr>
<td>p_des</td>
<td>desired pressure</td>
<td>[bar]</td>
</tr>
<tr>
<td>PI driver</td>
<td>control block of the driver, includes a P- and I-action</td>
<td>-</td>
</tr>
<tr>
<td>p_LU</td>
<td>lock up pressure</td>
<td>[bar]</td>
</tr>
<tr>
<td>p_p</td>
<td>primary pressure</td>
<td>[bar]</td>
</tr>
<tr>
<td>p_p_des</td>
<td>desired primary pressure</td>
<td>[Pa]</td>
</tr>
<tr>
<td>p_s</td>
<td>secondary pressure</td>
<td>[bar]</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>p_s_des</td>
<td>desired secondary pressure</td>
<td>[Pa]</td>
</tr>
<tr>
<td>p_dri_filt</td>
<td>filtered pressure of the drive</td>
<td>[bar]</td>
</tr>
<tr>
<td>T_brake</td>
<td>torque on the brakes</td>
<td>[Nm]</td>
</tr>
<tr>
<td>rel. em. button</td>
<td>release of the emergency button or not</td>
<td>-</td>
</tr>
<tr>
<td>Tc_est</td>
<td>estimated engine torque</td>
<td>[Nm]</td>
</tr>
<tr>
<td>temp_d_cl</td>
<td>temperature of the drive clutch</td>
<td>[°C]</td>
</tr>
<tr>
<td>temp_dri</td>
<td>temperature of the drive</td>
<td>[°C]</td>
</tr>
<tr>
<td>temp_p</td>
<td>temperature of the primary pulley</td>
<td>[°C]</td>
</tr>
<tr>
<td>temp_s</td>
<td>temperature of the secondary pulley</td>
<td>[°C]</td>
</tr>
<tr>
<td>T_IIr</td>
<td>torque of engine; for test bench use only</td>
<td>[Nm]</td>
</tr>
<tr>
<td>TqC</td>
<td>torque converter</td>
<td>-</td>
</tr>
<tr>
<td>T_w</td>
<td>torque to the wheels</td>
<td>[Nm]</td>
</tr>
<tr>
<td>v_des</td>
<td>desired speed</td>
<td>[km/h]</td>
</tr>
<tr>
<td>void</td>
<td>empty channel</td>
<td>-</td>
</tr>
<tr>
<td>v_v</td>
<td>vehicle speed</td>
<td>[km/h]</td>
</tr>
<tr>
<td>w_p</td>
<td>primary pulley speed</td>
<td>[rad/s]</td>
</tr>
<tr>
<td>w_p_min</td>
<td>minimal primary pulley speed</td>
<td>[rad/s]</td>
</tr>
<tr>
<td>w_s</td>
<td>secondary pulley speed</td>
<td>[rad/s]</td>
</tr>
</tbody>
</table>

Documentation of the control software in the VW Bora
Chapter 1  Control scheme of the software

In this chapter an overview of the car with the Zero Inertia powertrain is given. Every block is clarified and then it is possible to give the Simulink schemes.

1.1 Overview of the VW Bora

To get a better understanding how the powertrain is controlled a schematic picture is given of the Volkswagen Bora. This is shown in figure 1.1. The engine, CVT and flywheel are placed in the front of the car. In figure 1.2 the ZI powertrain concept layout is given. Appendix 39 gives the technical drawing of the standard CVT with the position of a few sensors. The control box, named “dSPACE”, is placed in the back of the car, because of lack of space under the hood and accessibility matters. The box contains a complete computer and signal processor, which controls the ZI powertrain. It operates through a separate battery to make sure the control unit is isolated from the vehicles own electric circuit. The dSPACE box consists of a processor board and multi channel in- & outputs. The dSPACE program is written in Simulink. This Simulink model is translated into C and subsequently compiled for and downloaded to the processor on the processor board.

In the interior, well within drivers reach, an emergency button is placed. Because this is still an experimental vehicle such a button is needed to stop the entire control process if the driver notices something goes wrong. This can be seen on the “Cockpit Module” running on a laptop computer. The driver can also prescribe values for certain control variables. The entire process will be described in more detail in the next chapter.

Figure 1.1: Schematic view

Figure 1.2: ZI powertrain concept layout
For controlling the ZI powertrain a number of sensors are placed near or at different components (also shown in figure 1.1). In appendix 2 the sensors and their calibration are listed. There were 3 sensors placed to measure respectively the lock up pressure, auxiliary pressure and the lubricant pressure, even though they broke down they are still placed on the transmission to prevent leakage.

In appendix 40 an overview of the electric scheme that is designed for the actuators used in the VW Bora is placed for documentation only. No explanation will be given.

1.2 Main blocks

The control software is developed in Simulink (MATLAB). In Figure 1.3 the main scheme is given. Different colors are used to make a difference between the functions of the blocks. The white blocks contain muxed signals and interfaces with dSPACE. The green blocks calibrate or filter these signals for further use. In the blue block the signals are rearranged for use in the yellow and orange/red blocks. In the yellow blocks the signals are processed and finally the safety functions are put together in the orange/red block.

For easy use, the paragraphs numbers are displayed near the corresponding blocks.

This report is limited concerning dSPACE. The white blocks gather their data from dSPACE, but it goes beyond the scope of this report to describe how dSPACE operates. Instead, the white blocks are decomposed to display the inputs (variables) used.

In the next paragraphs the white, green, red and blue blocks are decomposed. The two yellow blocks are decomposed in chapter 2 and 3.
1.3 Signals Calibration & Filtering Block

In this block all 39 input signals are calibrated. Some are filtered for further use in the next block called "Diagnostics & Demux" or terminated. In Appendix 3 the decomposed version of the block is shown. For surveyability the inputs are divided into 4 categories. In the next subparagraphs these four categories are clarified and decomposed. Some figures contain colored tag. This means a more detailed version of this figure is shown in the appendix with the corresponding number.

1.3.1 MUX_ADC

By further decomposing (DEMUX) the MUX_ADC according to figure 1.4 (see also Appendix 4) it can be seen that only 11 of the 19 analogue sensors are used. The signals that are used contain the essential data for controlling the powertrain. The other sensors are placed for monitoring purpose.

Each signal will require filtering or calibration for further use. In Appendix 3 is shown that for signal 1 to 19 (if necessary) a subsystem is introduced, named "Sub". In this subsystem a signal is manipulated.

If you look at the top of appendix 3 there is a output signal 1 which has subscript 'void', meaning an empty channel. This is the same for sensor 16. New sensors may be connected to these lines in the future.

First all signals from the sensors are filtered using a 1st order filter. This filtering process is under the block numbers Sub1 to Sub19. After undergoing a ZOH (Zero-Order Hold) function the signal is calibrated or sent to an output channel. ZOH functions are used to convert continuous-time signals to sampled signals for analyzing sampled continuous-time systems. In this case it is used to resample the signals from a higher rate (2.5 kHz) to lower rates (100 and 500 Hz). For signals 1, 3, 9 and 19 the filtering process is given in figure 2.5. For signals 2, 4, 5, 6, 8, 10 till 15, 17 and 18 this process are given in figure 1.6.

![Figure 1.4: MUX_ADC](image)

**Figure 1.4: MUX_ADC**

The use of "tau_fast" and "tau_slow" is needed, because the signals operate on 2 different sample rates, namely 100 and 500 Hz. For the low frequency "tau_slow" is used, for the high frequency "tau_fast". The values of τ are tau_slow = 0.0080 and tau_fast = 0.0016. For signal 7 a slight different filtering process is used. This is shown in figure 1.7. Sensor 1 measures the pressure on the primary pulley \( p_p \) [bar] and calibrated according to

![Figure 1.5: Process for different signals](image)

**Figure 1.5: Process for different signals**

![Figure 1.6: Process for different signals](image)

**Figure 1.6: Process for different signals**

![Figure 1.7: Process for signal 7](image)

**Figure 1.7: Process for signal 7**

with: \( \text{den}(s) = \tau \_\text{slow} \cdot 2 \cdot s + 1 \)
Documentation of the control software in the VW Bora

[Calibration 1, see Appendix 5]. After this, the signal is send to output 3.

Sensor 2 measures the temperature of the primary pulley temp_p [°C]. The signal is calibrated [Calibration 2] and terminated. To calibrate sensor 2 experiments are done and data from those experiments are placed in a table. For other signals the same procedure is followed for calibration.

The pressure on the secondary pulley p_s [bar] is measured by sensor 3. It is calibrated [Calibration 3] and sent to output 4.

For sensor 4 the same procedure from signal 2 is followed, but this sensor measures the temperature of the secondary pulley temp_s [°C] and calibrated by [Calibration 4].

Sensor 5 measures the pressure of the drive p_dri [bar]. It is calibrated [Calibration 5] and then filtered (see figure 1.8). The filter is using a preset bandwidth, which is given, in the most left lower block of figure 1.8.

Sensor 6 measures the temperature of the drive clutch (temp_dri [°C]). The calibration is similar as for signal 2 [Calibration 6] and is sent to output channel 9.

For Sensor 7 the signal of the drive pedal angle ang_dp [°] is sent to output channel 7, after calibration [Calibration 7].

The signal from sensor 8 (brake pedal trigger) doesn’t need any calibration, but is filtered according to figure 1.6 and then sent to output channel 8.

The angle of the throttle valve ang_tv [°] is measured by sensor 9, calibrated by [Calibration 9] and sent to output channel 6.

The pressure of the lock up p_LU [bar] is measured by sensor 10 for monitoring. Calibration 10 is used, but there is a rough correction of 1.7 bar and is not in service.

Sensor 11 is not in service, but can be used for measuring the auxiliary pressure p_aux [bar] and then calibration 11 is needed.

The pressure of the torque converter p_TqC [bar] is monitored by sensor 12 after using [Calibration 12]. This sensor is not in service.

The acceleration of the vehicle a_veh [m/s²] is not essential for the control of the powertrain, so it is monitored by sensor 13 and [Calibration 13]. Sensors 14 and 15 are not in service, but they can be used for measuring respectively the bearing and housing temperature. The calibration is the same [Calibration 14 and 15]. For safety an emergency button (sensor 17) is placed on output channel 10. Sensor 18 measures the following distance between the VW Bora and a vehicle in front of the Bora and sent to output signal 11. This is for monitoring only.

And finally the torque on the drive shaft T_w [Nm] is measured by sensor 19, and calibrated [Calibration 19] and sent to output signal 2.

The essential 11 signals together with the signals from MUX_CH, MUX_I/O and MANAL are put together with “MUX” and sent to “Diagnostics & Demux” block, see appendix 3.
1.3.2 MUX-CH

The MUX_CH outputs 10 channels (see figure 1.9), some channels are merely throughputs from the input channels (MUX_CH). There are 6 input channels, which can be seen in appendix 5.

First all signals are filtered the same way as in paragraph 1.3.1 according to figure 1.6, except the lowest signal fcn. The engine speed $N_e$ [rpm] is measured using a magneto resistive element (Hall sensor). The flanks passing through per second are counted in the dSPACE I/O card. The number “60/135” is necessary to convert the number of flanks into revolutions per minute. The number “60” stands for 60 seconds and “135” are the number of flanks per revolution. For the derivative another filter (filter bandwidth 1 Hz) and saturation (to limit the range from 400 to 10000) are necessary. Further a discrete derivative function in block is used to obtain the derivate numerically.

![Figure 1.9: MUX_CH](image)

For the speed of the primary and secondary pulley, respectively $N_p$ and $N_s$, the process is the same as for the engine speed, but the number of flanks/rev is different, respectively “22 flanks/rev” and “12 flanks/rev”, see appendix 5.

For the turbine speed $N_t$ [rpm] no derivative is needed. The process for determining the speed is the same as the preceding signals, the flanks per revolution is 22.

The revolutions of the rear wheel are determined in the same way as figure 1.10, but now there are 8 flanks per revolution.

![Figure 1.10: process for $N_e$](image)

The process “FILT” is a 1st order filter, which filters the signal above 1 Hz.

The ratio between the primary and secondary pulley speed $i$ and its derivative dot $i$ is determined as in figure 1.11. The general function of the product block is: the product of the inputs with the sign “x” are divided by all inputs marked with “+”. In this case $N_p$ divided by $N_s$. The switch operates as followed: when the middle input values is greater or equal to a certain user defined threshold value (here: 0.5), then the upper input i.e. the computed ratio is used, if not the lowest input channel is used i.e. the ‘low’ ratio $i_{low}$.

![Figure 1.11: Determination of $i$](image)
1.3.3 MUX_I/O

The MUX_I/O outputs from digital I/O boards, see figure 1.12. The inputs for this block are:

- DNR_D: the drive of the DNR-set
- DNR_N: the neutral of the DNR-set
- DNR_R: the reverse of the DNR-set

Three micro switches detect when the transmission is put in the D, N or R and these on/off signals are send to the MUX_I_O.

![Figure 1.12: MUX_I/O](image)

1.3.4 MANUAL

Altering dialogs in the afore mentioned “COCKPIT” (see “CONTROLS” in appendix 6) running on a laptop, the driver can directly manipulate some variables to a certain value. These variables are sent through “MANUAL” (see figure 1.13). The following signals can be changed (see appendix 7 for the Simulink version):

- void: empty channel
- Cockpit Release Button: to release the emergency button
- i_d: desired ratio setpoint
- dot_i_d: derivative of i_d
- ang_dp: drive pedal angle
- T_brake: the amount of torque on the brakes (test rig only)
- drive: to put the transmission in “drive”
- LU: to activate the lock up clutch
- reset: possibility to reset the integrator in the “CVT Ratio Setpoint” (see appendix 18)
- ratio on/off: to enable/disable the CVT ratio set point control module
- Engine Start: to start the engine (test rig only)
- v_des on/off: to enable/disable a cruise controller
- Virtual Driver On/Off: enable/disable a virtual driver (driving a predefined drive cycle)
- Foot Pedals On/Off: enable/disable drive pedal sensibility
- N_p_min: minimal setpoint of the primary pulley

![Figure 1.13: Inputs from MANUAL](image)
1.4 Diagnostics & Demux Block

In the “Diagnostics & Demux” block 39 signals from “Signals Calibration & Filtering” are divided into 4 groups. They are divided into “Coordinated Control”, “Component Controllers”, “Monitors Signals” and “Safety Controls”. The main difference between the ‘Coordinated Control’ and the “Component Controllers” is the frequency on which they operate. The first uses signals of a frequency of 100 Hz, the latter of 500 Hz. In figure 1.14 it is schematically shown how the signals are divided. In appendices 8 to 11 the four groups are further decomposed.

Figure 1.14: Schematic division of Diagnostics and Demux
1.5 Monitors

This block receives signals from most of all the blocks and merely outputs them again as "monitors". In figure 1.15 this is schematically shown. The Simulink blocks are given in appendix 12. The function of the block "Monitors" is that the output signals can be picked up by the cockpit module (appendix 6) or the dSPACE "Trace" module to write signal streams to a hard disk.

![Figure 1.15: Schematic view of inputs monitors]

1.6 Safety Controls

The safety controls (see figure 1.16) are needed to prevent belt slippage. By computing the maximal allowable torque at the primary pulley and comparing it with the actually transmitted torque, the safety margin can be determined. If the margin is trespassed, the automatic emergency stop inhibits. In that case the electronic engine throttle closes immediately and the drive clutch is opened, altogether resulting in zero torque transmitting of the CVT.

Also it is possible to stop the process manually by pressing the emergency button at the cockpit at wish of the driver. Apart from this, there is also a "hard" button in the vehicle’s interior that opens the current circuits to the engine throttle and drive clutch solenoid.

In appendix 13 the Simulink scheme for the safety controls is displayed.

![Figure 1.16: Safety Controls]

1.7 Signals Out

In this block all the signals are put together and send to the dSPACE module (see figure 1.17 and appendix 14 for the Simulink scheme). Some signals have to be converted back to analogue signals (MUX_DAC: digital to analogue converter).
Chapter 2  Coordinated Control

In this chapter an explanation of the “Coordinated Control” block will be given. First the function of the main scheme is given schematically and after that more details are given.

2.1  Schematic overview and function

The inputs for the Coordinated Control are from the “Diagnostics & Demux” and “Safety Controls” blocks (see figure 2.1). The exact input signals from these blocks are shown in the main Simulink scheme for the Coordinated Control in appendix 15.

The Coordinated Control exists of 5 main control blocks, called “Driver”, “Drive Pedal Translation”, “CVT Ratio Setpoint”, “ICE Torque Setpoint” and “TqC Lock-Up Setpoint” (see appendix 15). These will be explained in the next paragraphs.

2.2  Driver

This block (see figure 2.2) translates the difference between the desired and actual vehicle speed to a pedal deflection. This speed can be obtained by a real driver or the virtual driver. This is shown in appendix 16. For control a “PI-driver” is needed, shown in appendix 17. ‘PI’ stands for the type of control is used. ‘P’ stands for a proportional action and ‘I’ for an integrating action.

2.3  Drive Pedal Translation

In this block (see figure 2.3) the role of the pedal deflection becomes apparent. The pedal deflection alpha is translated into a desired wheel torque T\_w\_des and desired power of the engine P\_w\_des. This is shown in appendix 18.

2.4  CVT Ratio Setpoint

The desired ratio of the CVT is processed using the inputs at the left side of the block in figure 2.4. In appendix 19 the Simulink version is shown. The essence of the CVT Ratio Setpoint lies in a dynamic function of w\_d\_dot (see equation 2.1). This function is a simplified version of the control law [equation 7.38, Serrarens]. For more info see [paragraph 8.3.2, Serrarens]

\[ w\_d\_dot = \frac{|u(4)| - |u(3)| \cdot u(1) \cdot iF}{0.6019677 - 0.6359925 \cdot u(2)} \]  

(Equation 2.1)
Documentation of the control software in the VW Bora

with:

- $u(1)$: input from channel 1; $i_{\text{des}}$
- $u(2)$: input from channel 2; saturated $w_{\text{d\_dot}}$
- $u(3)$: input from channel 3; $T_{\text{w\_des}}$
- $u(4)$: input from channel 4; $T_{\text{d}}$

In the "Computing and Restraining i" block, shown in appendix 20, the desired ratio is computed. There are 2 restraints when computing $i_{\text{des}}$. The first restraint is: the flywheel may not exceed 4000 rpm. The second is: when the emergency button is pushed, the CVT has to go to the medium ratio. The needed integrator inputs are shown in appendix 21.

### 2.5 ICE Torque Setpoint

In the "ICE Torque Setpoint" block (see figure 2.5) the desired engine torque and the corresponding angle of the throttle valve are determined. See appendix 22 for the Simulink version. In appendix 23 and 24 it is respectively shown how the torque is controlled by following the E-line or OD-line (overdrive line) and when the wide open throttle is enabled at kick-down. "ICE" stands for Internal Combustion Engine.

### 2.6 TqC Lock-Up Setpoint

The torque converter is required for smooth drive away performance. After vehicle launch it would unnecessarily consume power. For that reason the slipping torque converter is locked up, meaning that the impeller and turbine elements are being mechanically coupled. In this block (see figure 2.6, appendix 25 for Simulink version) it is decided if the torque converter should be locked up. It can be seen for $v > 20$ km/h that the torque converter will be closed, and if the vehicle speed becomes smaller than 15 km/h the torque converter will be opened.
Chapter 3 Component Controllers

In this chapter the “Component Controllers” block will be explained. First the inputs will be given and then more details of the process. Again the full Simulink versions are put in the corresponding appendices.

3.1 Inputs & outputs Component Controllers

The Components Controllers (see figure 3.1) receives its inputs from the Coordinated Controller, Diagnostics & Demux and Safety Controls. In appendix 26 is shown which signals from these inputs are necessary for the Components Controllers. In this control system a number of processes have to be controlled, which can be seen in appendix 26. They can be divided into 2 main systems (the blue text in the appendix): the ZI Transmission and the Throttle E-motor. The ZI Transmission stands for the control of the pump, torque converter, the variator and the drive clutch. The Throttle E-motor deals with the drive-by-wire throttle.

In the next paragraphs these 2 systems will be explained separately.

3.2 Throttle E-motor control

For better control of the ZI powertrain the normal gas pedal is replaced by a drive-by-wire system. When using a drive-by wire system the signal from the gas pedal deflection is used for control of the ideal engine torque transmitted through the ZI powertrain. This provides more freedom of control than using a normal cable. In figure 3.2 the simple Simulink version is given. The inputs needed for the drive-by wire are the desired throttle valve angle and the real throttle valve angle. These signals are processed according to appendix 27 and amplified and sent to Signals Out.

3.3 ZI Transmission

As mentioned above the “Component Controllers” block consists of 4 components; “Pump Mode”, “Variator mode”, “TqC PWM Lock-up steering” and “Drive Clutch control”. All these blocks will be briefly discussed in the next paragraphs.

3.3.1 Pump mode

The first, the “Pump mode”, determines if the pump needs to operate in single or double sided mode. The difference
between those two modes is the amount of oil flow produced by the pump. In appendix 23 the Simulink block shows the decision making for which mode to operate. The output (DS/SS) is also needed for the next component: Variator Control.

### 3.3.2 Variator Control

The Variator Control controls the CVT ratio. The CVT ratio depends on the pressure put on the primary and secondary pulley. A change of the pressures is a result of a change in the inputs shown in figure 3.4. The control process is shown in appendix 29. The blocks “Torque Transmission Control”, “Ratio Control”, “Ratio on/off Control” and “Pressure Control” are shown in detail in respectively appendix 30, 31, 32 and 33. The “Pressure Control” block contains a block for “Primary Pressure Control” and “Secondary Pressure Control”. These blocks are shown in Simulink details in respectively appendix 34 and 35. The small blocks from “Pressure Control”, named “soft reset p_s_des”, “pri actuator” and “sec actuator” are shown in appendix 36.

### 3.3.3 Torque converter PWM Lock-up steering

The torque converter is a part of the ZI transmission and its lock-up clutch is controlled too. Since an open, thus slipping torque converter consumes energy it needs to be locked up after the vehicle has launched. The difference with paragraph 2.6 (TqC Lock-Up Setpoint) is that for this block there is a possibility for Pulse Width Modulation (PWM) and a check is made to see if the torque converter is really closed. The inputs needed to decide the lock-up moment are shown in figure 3.5, the Simulink version is shown in appendix 37.

### 3.3.4 Drive Clutch control

This block is a part of the “TqC PWM LU steering”. If this clutch closes, the turbine engine is coupled to the torque converter. See figure 3.6 for inputs and the Simulink version is shown in appendix 38. In figure 3.7 it is schematically shown how the components are coupled together.

---

**Figure 3.4: Variator Control**

- DS,SS
- rar, button
- ratio on/off
- p_p
- p_s
- N_p
- N_s
- A.29
- L_1 out [A]
- L_2 out [A]
- T_e_est
- drive
- LU Closed
- p_p_des

**Figure 3.5: TqC PWM LU**

- LU
- O/C out
- N_p
- A.37
- N_e
- TqC closed

**Figure 3.6: Drive Clutch Control**

- drive
- A.38
- L_dri out
- N_t

**Figure 3.7: Coupling of components by clutches**
Appendix 1 References


- Component Control for the Zero Inertia Powertrain, Bas G. Vroemen, ISBN 90-386-2593-6, 2001
### Appendix 2 Sensors & Calibration functions of the analogue sensors

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Type</th>
<th>Quantity</th>
<th>Var.</th>
<th>Signal condit.</th>
<th>Digital conv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kulite HKM-375; 0-70 bar</td>
<td>primary pressure</td>
<td>p</td>
<td>Keithley MB38-07</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>1a</td>
<td>temperature pick up from 1</td>
<td>primary temperature</td>
<td>T</td>
<td>Keithley MB41-01*</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>2</td>
<td>Kulite HKM-375; 0-70 bar</td>
<td>secondary pressure</td>
<td>p</td>
<td>Keithley MB38-07</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>2a</td>
<td>temperature pick up from 2</td>
<td>secondary temperature</td>
<td>T</td>
<td>Keithley MB41-01*</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>3</td>
<td>Kulite HKM-375; 0-14 bar</td>
<td>drive clutch pressure</td>
<td>p</td>
<td>Keithley MB38-07</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>3a</td>
<td>temperature pick up from 3</td>
<td>drive clutch temperature</td>
<td>T</td>
<td>Keithley MB41-01*</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>4</td>
<td>Data instruments EA200; 0-35 bar†</td>
<td>lock-up pressure</td>
<td>p_LU</td>
<td>Keithley MB41-02</td>
<td>MUX_ADC</td>
</tr>
<tr>
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<td>Data instruments EA200; 0-35 bar†</td>
<td>auxiliary valve pressure</td>
<td>p_aux</td>
<td>Keithley MB41-02</td>
<td>MUX_ADC</td>
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<td>6</td>
<td>Data instruments EA200; 0-35 bar†</td>
<td>lubricant pressure</td>
<td>p_lub</td>
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<td>Philips KMI 10/1</td>
<td>primary speed</td>
<td>N</td>
<td>opto-isolation</td>
<td>MUX_ADC</td>
</tr>
<tr>
<td>8</td>
<td>Philips KMI 10/1</td>
<td>secondary speed</td>
<td>N</td>
<td>opto-isolation</td>
<td>MUX_ADC</td>
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<tr>
<td>9</td>
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<td>N</td>
<td>opto-isolation</td>
<td>MUX_ADC</td>
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<td>drive shaft momentum</td>
<td>M</td>
<td>MICRODAS BW2</td>
<td>ADC</td>
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<td>11</td>
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<td>ang dp</td>
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<td>ADC</td>
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<td>D/I/O</td>
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<tr>
<td>13</td>
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<td>D-indicator</td>
<td>DNR_D</td>
<td>Keithley IDC-05</td>
<td>D/I/O</td>
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<td>D/I/O</td>
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<td>R-indicator</td>
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<td>ADC</td>
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<td>throttle position angle</td>
<td>throttle angle</td>
<td>Keithley MB40-03</td>
<td>ADC</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>ACTUATORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 proportional solenoid</td>
</tr>
<tr>
<td>2 proportional solenoid</td>
</tr>
<tr>
<td>3 proportional solenoid</td>
</tr>
<tr>
<td>4 on/off solenoid</td>
</tr>
<tr>
<td>5 on/off solenoid</td>
</tr>
<tr>
<td>6 on/off solenoid</td>
</tr>
<tr>
<td>7 tempomaat stepper motor</td>
</tr>
</tbody>
</table>

* To increase the accuracy of the temperature transducing, the output signals should be debiased with -5V at room temperature to make the MB41-01 neatly cover the output range: -266 – 364 mV
* ¥ An own design signal amplifier is built
† out of order, but still in place.

### The Calibration for the sensors:

**Calibration 1:**

- primary pressure: Kulite 5938-3A-312, 70 bar
- \(5 \cdot 15.1009 \cdot u[1] - 1.1844 - 0.167\)

**Calibration 2:**

- primary temperature: Kulite 5938-3A-312, 70 bar
- Look-up table

**Calibration 3:**

- secondary pressure: Kulite 5938-3A-311, 70 bar
- \(5 \cdot 15.1373 \cdot u[3] - 0.971 + 0.26\)
Calibration 4: secondary temperature; Kulite 5938-3A-311, 70 bar
\[5 \cdot 2.9439 \cdot u[5] - 0.0334\]

Calibration 5: pressure drive clutch lock; Kulite 6183-6-282, 14 bar
\[5 \cdot 7.0804 \cdot u[10] - 7.4134 + 1.7\]

Calibration 6: temperature drive clutch lock; Kulite 6183-6-282, 14 bar
Look-up table

Calibration 7: drive pedal angle; look-up table

Calibration 9: throttle opening; look-up table

Calibration 10: lock up pressure; DI 98232-5Y0F01, 35 bar
\[5 \cdot 7.0804 \cdot u[10] - 7.4134 + 1.7\] rough correction +1.7 bar!

Calibration 11: auxiliary pressure; not in service

Calibration 12: pressure torque converter; DI 98321-600V01, 35 bar
\[6 \cdot 8818.5 \cdot u[12] - 7.2816\]

Calibration 13: vehicle acceleration; Kistler K-beam 8303A2

Calibration 14: PT100; temperature sensor

Calibration 15: PT100; temperature sensor

Calibration 17: emergency button

Calibration 18: distance system; Riegl

Calibration 19: torque drive shaft; Volland telemetry
\[2 \cdot [5 \cdot 313.2478 \cdot u[19] + 26.8046]\]
Appendix 4 “Signals Calibration & Filtering Analogue Sensors”
Appendix 5 “Signals Calibration & Filtering|Channels”
Appendix 6 Cockpit (dSPACE) module

A cockpit module – running at a laptop in the vehicle’s interior - monitors the main signals. Some user appointed variables could be manipulated to a certain value through dialog boxes.
Appendix 7 "Signals Calibration & Filtering\Inputs from Cockpit"
Detailed version how the "idle/standby" block operates
Appendix 9 “Diagnosis & Demux” Diagnosis for Safety Controls

Detailed version how the “detect TqC lock” block operates

Mechanical Engineering – DCT 2002.51
Appendix 10 “Diagnosis & Demux\Diagnosis for monitor signals”
Appendix 12 “Monitors”

Diagram of the control software in the VW Bora.
Appendix 13 “Safety Controls”
Appendix 14 “Safety Controls\Signals out”
Appendix 15 “Coordinated Control”
Appendix 16 “Coordinated Control\Driver”

Virtual or real driver

Mechanical Engineering – DCT 2002.51
Appendix 17 “Coordinated Control\Driver\PI driver”
Appendix 18 "Coordinated Control\Drive pedal translation"
Appendix 19 “Coordinated Control\CVT Ratio Setpoint1”
Appendix 20 “Coordinated Control\CVT Ratio Setpoint1\_d”
Appendix 21 "Coordinated Control\CVT Ratio Sepoint\integrator inputs"
Appendix 22 "Coordinated ControlICE Torque Setpoint"
Appendix 23 “Coordinated ControlICE Torque Setpoint1\control torque”
Appendix 24 “Coordinated Control\ICE Torque Setpoint1\Kick down”
Appendix 25 “Coordinated Control\TqC Lock-Up Setpoint”

LU manual
Appendix 27 "Component Controllers\Throttle E-motor"
Appendix 28 "Component Controllers\ZI TransmlPump mode control"
Appendix 29 “Component Controllers\ Z1 Transm\ Variator Control”
Appendix 30 "Component Controllers\Z\ Transm\Variator Control\Torque control"
Appendix 31 "Component Controllers\Z\ Transm\Variator Control\Ratio control"
Reset conditions:
Appendix 32 "Component Controllers\ZI Transmi\Variator Control\Ratio on/off control"
Appendix 33 "Component Controllers\ZI Transm\Variator Control|p control"
Appendix 34 “Component Controllers\ZI Transm\Variator Control\p control\p_p control”
Appendix 35 "Component Controllers\ZI Transmi\Variator Controlp controlp_s control"
Appendix 37 "Component Controllers\ZI Transm\TqC PWM LU"
Appendix 38 “Component Controllers\ZI Transm\Drive Clutch Control”
Appendix 39 Technical drawing CVT with sensors
Documentation of the control software in the VW Bora

Mechanical Engineering – DCT 2002.51