Auxiliary Cold Start System and Powertrain Control Module Interface Validation through Hardware in the Loop System

Leandro dos Santos Scarazzato
Claudio Guercio Labate
Alexandre Ubida
Caroline Augusti
Fernando Sarracini Júnior
Ford Motor Company Brasil Ltda.

ABSTRACT

Hardware in the Loop (HiL) testing is a simulation technique where the PCM (Powertrain Control Module) is connected to a test bench. The engine behavior is emulated through an engine model inside the HiL virtual environment. This technique avoids vehicle testing and allows to run thousands of scenarios at low cost and reduced timing. The new Brazilian PROCONVE L7 regulation imposes NMOG (Non-Methane Organic Gases) emissions limit and unburned ethanol discount will not be allowed. It is a recognized challenge to meet NMOG emissions limit when running hydrated ethanol (E100 fuel) in port fuel injection engines. To overcome this, an Auxiliary Cold Start System (ACSS) can be applied to heat the E100 prior to cranking and during engine warmup, which improves combustion quality. The interface between ACSS and PCM requires functional validation. This study proposes to improve the HiL environment by creating the ACSS model, which needs to be integrated with the current model-based system. The ACSS model development will be based on the analysis of requirements, architecture design and functional logic definition. This paper will evaluate the portion of the PCM software which controls the ACSS, verifying software responses for each error state, message synchronization and heating cycles.

INTRODUCTION

Automotive industry competitiveness requires an increase in efficiency and cost reduction. New regulations like the PROCONVE L7 (PL7) require additional development effort and feasible finance solutions. The close relationship between technology companies and the auto industry contributes to the expansion of the boundaries of the traditional market. Customers are evolving, and gradually changing the mindset of impulsive consumption, forcing automakers to innovate in search of excellence and to remain competitive in the market [1].

The use of computational tools is essential for developments with shorter duration and lower costs, which is reflected in competitive advantages. For this work, the following computational applications were used: Matlab v2015b, ATI VISION 5.2.1, dSPACE ControlDesk 6.1.

Figure 1 shows dSPACE PHS HiL equipment which is installed at the Ford Tatuí Development Center.

Figure 1. HIL Equipment at Tatuí Development Center.

The ACSS has the purpose of controlling and monitoring the heaters inside the fuel rail [2], [3]. The PL7 NMOG emissions limit will require Port Fuel Injection (PFI) flex fuel engines to heat the hydrated ethanol for engine startup fueling because unburned ethanol discount is being phased out [4]. Heating the E100 is necessary to assure fuel burning and good combustion quality due to the higher flash point when compared to gasohol (E22 fuel) [5]. The flash point is the lowest temperature at which a liquid will form a vapor in the air near its surface that will "flash," or briefly ignite, on exposure to an open flame. The PCM delays the engine crank until optimal fuel temperature is achieved, this is called "pre-heating time".

Figure 2 shows the Auxiliary Cold Start System Module which presents:

- Four input circuits: high power supply, low power supply, pulse-width modulation (PWM) control and ground;
- Five output circuits: one for diagnosis and up to four outputs for each heater. It is important to note

that there is only one unique output circuit from the ACSS that provides the power feedback and error states to the PCM.

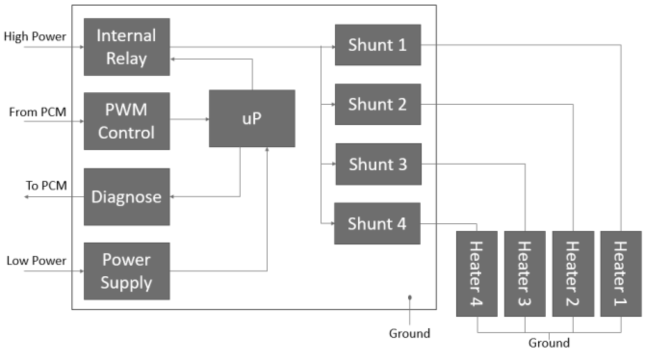


Figure 2. ACSS Module Functional Diagram.

The scope of this work is to model the ACSS diagnostic output using Matlab/Simulink and embed this model in the dSpace HiL bench, to provide this signal to PCM and verify if the PCM is acting according to expectation. The PCM is tricked into behaving as if it is physically connected to an ACSS. With the PCM fuel temperature model running, not the scope of this paper – proprietary information, several scenarios are tested such as triggering fault codes, applying different pre-heating times, different numbers of fuel cycles and crank delays.

During the pre-heating time, while the crank is being delayed, the driver is notified that fuel heating is happening through an ACSS telltale in the cluster (see Figure 3). In the event of a fault, a Malfunction Indicator Lamp (MIL) is illuminated (see Figure 4).

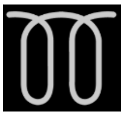


Figure 3. ACSS telltale.

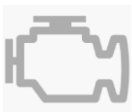


Figure 4. Malfunction Indicator Lamp (MIL).

A CAN monitor connected to the system checks if the ACSS telltale is requested to be illuminated during the heating cycle. Also, it is verified if MIL is requested to turn on when a fault is generated.

EXPERIMENTAL SETUP AND MODELLING

Figure 5 shows the complete proposed assembly schematics for testing.

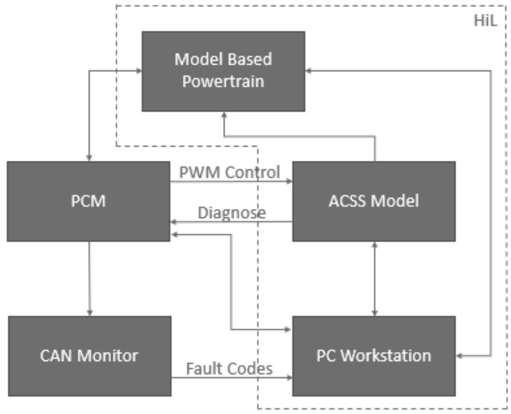


Figure 5. Block Diagram for this project.

ACSS DIAGNOSTIC SIGNAL MODELLING

The ACSS diagnostic signal is a bit frame with the following structure:

- a synchronization stream: fixed sequence of bits;
- a heater identification stream: identifies the defective heater.
- a failure identification stream: identifies failure type. It can be associated with each heater or general failure (e.g., overtemperature, microprocessor failure, overvoltage, relay sticking);
- an even parity check bit: verifies if the total number of 1-bits in the string is even [6]. At Simulink, Ex-OR gates connections were used to generate even parity bit (see Figure 6);
- a power feedback stream: contains the actual ACSS delivered power. Figure 7 shows the Simulink model for ACSS power feedback.

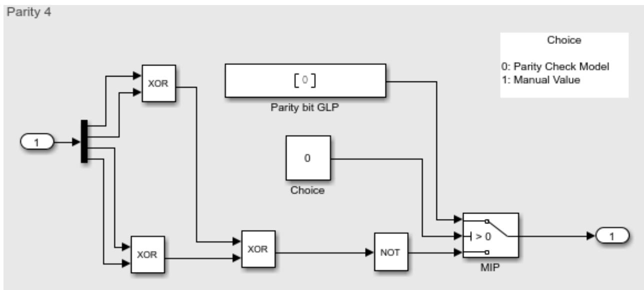


Figure 6. Example of parity bit calculation for 4 bits.

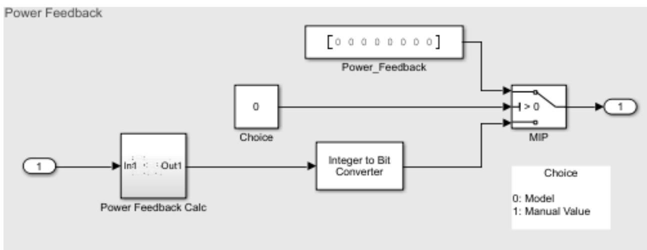


Figure 7. ACSS power feedback model.

For proper signal processing, the PCM requires ACSS diagnostic bit-frame reception synchronized with PWM control.

Having defined the diagnostic bit frame, the ACSS model could be incorporated into the current model-based powertrain HiL. Since heater modelling is out of the scope of this paper, the PWM control output provided by PCM is copied and converted to the power feedback stream provided by the model (see Figure 5).

RESULTS AND DISCUSSION

To validate the developed ACSS model, the same PWM control PCM signal (yellow trace in Figure 8) was sent in parallel to both the ACSS model and the ACSS physical part (connected to known heaters). Using a scope, the ACSS output diagnostic signal generated by the model (green trace in Figure 8) was compared to the physical ACSS signal (blue trace in Figure 8). It was confirmed that the model accurately replicated the physical ACSS.

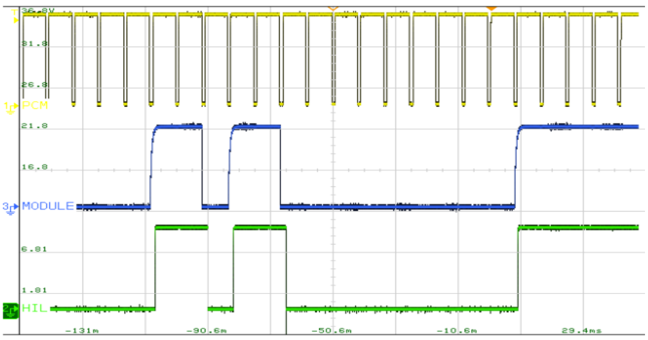


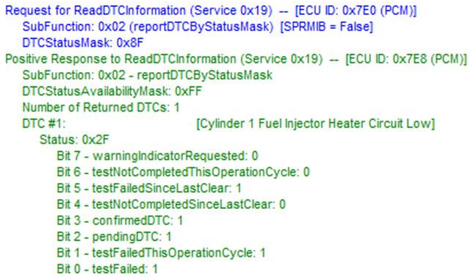
Figure 8. Comparison between the ACSS model and physical part.

The PCM monitors the quality of the ACSS diagnostic bit frame. To confirm the robustness of the ACSS model, some constant bit frames were defined and uninterruptedly broadcasted to the PCM for a couple of hours. Using ATI VISION 5.2.1, the PCM internal error counter for bit frame reception was monitored and the counter did not indicate any issue.

After the ACSS model was proven to be robust, the PCM response for two different error states was verified:

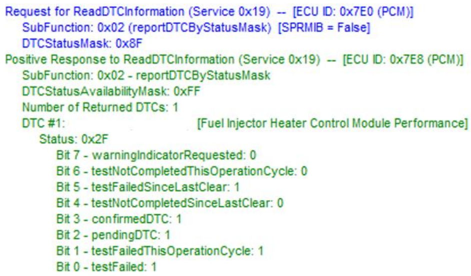
- heater short circuit to ground of cylinder #1 (see Figure 9);
- ACSS internal error where relay is sticky (see Figure 10).

After faults were induced, the error codes were collected from PCM through OBD-II port.



Request for ReadDTCInformation (Service 0x19) -- [ECU ID: 0x7E0 (PCM)]
SubFunction: 0x02 (reportDTCByStatusMask) [SPRMIB = False]
DTCStatusMask: 0x8F
Positive Response to ReadDTCInformation (Service 0x19) -- [ECU ID: 0x7E8 (PCM)]
SubFunction: 0x02 - reportDTCByStatusMask
DTCStatusAvailabilityMask: 0xFF
Number of Returned DTCs: 1
DTC #1: [Cylinder 1 Fuel Injector Heater Circuit Low]
Status: 0x2F
Bit 7 - warningIndicatorRequested: 0
Bit 6 - testNotCompletedThisOperationCycle: 0
Bit 5 - testFailedSinceLastClear: 1
Bit 4 - testNotCompletedSinceLastClear: 0
Bit 3 - confirmedDTC: 1
Bit 2 - pendingDTC: 1
Bit 1 - testFailedThisOperationCycle: 1
Bit 0 - testFailed: 1

Figure 9. Stored PCM error code associated with the heater of cylinder #1.



Request for ReadDTCInformation (Service 0x19) -- [ECU ID: 0x7E0 (PCM)]
SubFunction: 0x02 (reportDTCByStatusMask) [SPRMIB = False]
DTCStatusMask: 0x8F
Positive Response to ReadDTCInformation (Service 0x19) -- [ECU ID: 0x7E8 (PCM)]
SubFunction: 0x02 - reportDTCByStatusMask
DTCStatusAvailabilityMask: 0xFF
Number of Returned DTCs: 1
DTC #1: [Fuel Injector Heater Control Module Performance]
Status: 0x2F
Bit 7 - warningIndicatorRequested: 0
Bit 6 - testNotCompletedThisOperationCycle: 0
Bit 5 - testFailedSinceLastClear: 1
Bit 4 - testNotCompletedSinceLastClear: 0
Bit 3 - confirmedDTC: 1
Bit 2 - pendingDTC: 1
Bit 1 - testFailedThisOperationCycle: 1
Bit 0 - testFailed: 1

Figure 10. Error code associated to ACSS sticking relay.

The PCM behaves as expected with the induced errors, setting and storing the proper failure codes.

The developed ACSS model is also able to simulate different pre-heating time conditions, replicating the physical behavior of the system at colder temperatures. In practice, the lower the ambient temperature, the longer it takes to heat the fuel to achieve a target temperature and release the engine crank.

When the driver opens the vehicle door or turns the ignition key to crank the engine, the PCM requests the ACSS to deliver power to heat the fuel. The ACSS model reacts to this stimulus and provides the power feedback being applied back to PCM. The PCM considers the informed power feedback from the ACSS to estimate the fuel temperature (see Figure 11).

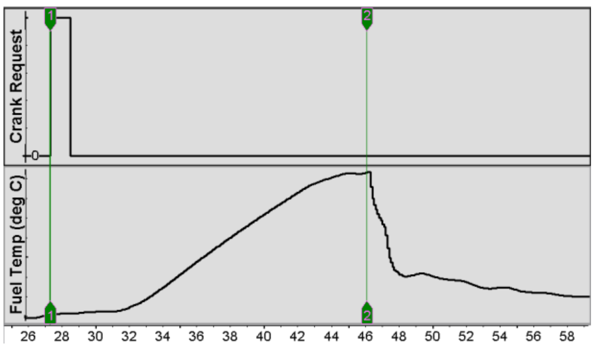


Figure 11. Engine crank request and PCM estimated fuel temperature.

When the estimated fuel temperature reaches the desired value, the crank is released and the engine starts (see Figure 12).

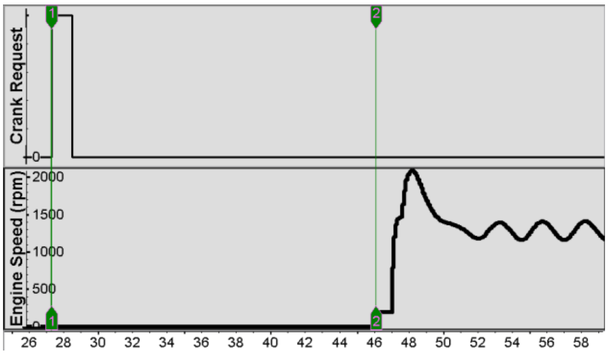


Figure 12. Engine startup is delayed and crank is released when fuel target temperature is achieved.

SUMMARY / CONCLUSIONS

The bench testing strategy proposed in this paper not only increases software robustness (since all error state scenarios can now be induced using the ACSS Model) but also reduces the PCM validation timing significantly from weeks to a few hours.

For further improvements, the following tools could be implemented:

- test automatization, making every possible single bitstream combination and verifying the PCM reaction;
- test automatization by making the system automatically test the PCM behavior for different engine coolant temperatures and pre-heating times, simulating ideal heaters (which deliver exactly the same amount of power that is requested).
- Non-ideal heaters (which deliver less power than requested by PCM) test and impact evaluation on pre-heating time and PCM response. Example: how long the engine crank would be delayed in case of applying a set of heaters that deliver 90% of requested power.

This paper confirmed the HiL equipment capability for interface validation between the PCM and the ACSS, reducing the demand for physical prototype vehicles, cold chamber usage and ACSS special parts. Because a single prototype vehicle can cost hundreds of thousands of dollars, all alternative solutions are very important to help increase competitiveness during product development.

Regarding the studied system, all the obtained results met the project acceptance criteria and can be easily replicated on any other PCM interface which uses a bitstream for communication and SAE J2716 SENT communication protocol.

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DEFINITIONS / ABBREVIATIONS

ACSS	Auxiliary Cold Start System
CAN	Controller Area Network
E100	Hydrous Ethanol Fuel
E22	Brazilian reference gasohol fuel with 78% gasoline and 22% anhydrous ethanol
Flash point	Lowest temperature at which vapors above a volatile combustible substance ignite in air when exposed to flame
Flex Fuel	Able to be fueled with gasohol, hydrous ethanol or any mixture between both
HiL	Hardware in the Loop
MIL	Malfunction Indicator Lamp
NMOG	Non-Methane Organic Gases
PCM	Powertrain Control Module
PFI	Port Fuel Injection
PL7	PROCONVE L7
PWM	Pulse-width Modulation
SAE	Society of Automotive Engineers
SENT	Single Edge Nibble Transmission