

Hardware–In–Loop Test Bench Based Failure Mode Effects Test Automation

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Abstract: The after-treatment system is used to make exhaust gases less hazardous to environment. It consists of set of sensors and actuators. Due to harsh working condition, the system needs to be tested against large number of possible faults. The correct working of set of sensors and actuator is ensured with failure modes effects tests (FMET). The conventional manual FMET is time consuming and prone to manual errors. In order to reduce the testing time and manual errors the Hardware – in – loop (HIL) system is developed and automated. The HIL system uses NI TESTSTAND and NI LabVIEW to automate the conventional FMET process. The system is implemented on engine emulator called Load-box User Interface System (LUIS Bench) and FMET box. The developed Hardware – in – loop system is more accurate and reduces the testing time significantly.

Keywords: After-treatment, Hardware – in – loop system, Failure Modes Effects Tests and LUIS

I. INTRODUCTION

A very high horsepower engines such as 160HP, 60HP, 23Hp are used for heavy duty, medium duty and light duty vehicles. The dominant exhaust gases from these vehicles are Oxides of Nitrogen i.e. NO_x and particulate matters. It is a mixture of extremely small particles and liquid droplets which come out with exhaust gases from the automobile engine. Particulate matter is also known as particle pollution or PM. It is a mixture of extremely small particles and liquid droplets which come out with exhaust gases from the automobile engine.

In high horsepower engines, the particulate matters concentration is reduced within the engine itself making the compromise with increased NO_x. After-treatment system is necessary to control the environmental pollution due to emission of NO_x from this engine. In order to reduce the NO_x, urea solution is sprayed over the exhaust gases with the help of doser which convert NO_x into N₂ and H₂O (water). Urea solution called as diesel exhaust fluid contains 32.5% of urea and 67.5% of distil water. In order to provide the error free dosers the correct testing of the doser is required. The Hardware-in-loop system is developed and automated to reduce the testing time and to improve the testing results.

A. Hardware – in – loop system

The hardware – in – loop (HIL) testing can be used for great range of systems from simple embedded systems such as room temperature controllers to sophisticated embedded systems like the dosing system consisting of large number of sensors and actuators [1].

Figure 1 illustrates the generalized block diagram of HIL testing. The required system is simulated as the HIL

system and its operation is controlled through the connected controller. The hardware – in – loop system involves the advantage of the testing of embedded system in cost effective, repeatable and controlled manner. Even when the end system is not ready, the HIL methodology allows development of ECUs. If the vehicle is also ready in that case the HIL system reduces the iteration time. It is found that in automobile industries the testing of ECUs through HIL is easier and efficient than testing on real vehicle.

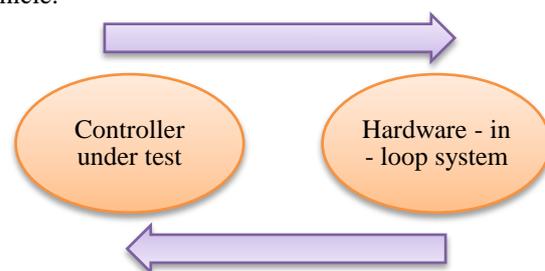


Fig. 1. Block diagram of generalize HIL system

As the probabilities of accident are more in real environment "in-vehicle" testing, the use of HIL, in development and validation of ECUs reduces human risk factor. The combination of virtual prototyping and physical environment can be described as a HIL system.

B. After – treatment system

There are three types of methods developed so far to reduce the hazardous exhaust gases coming out of engine –

- Exhaust Gas Recirculation (EGR)
- Diesel Particulate Filter (DPF)

- Selective Catalytic Reduction (SCR) technology

Exhaust Gas Recirculation (EGR) method was used as an after-treatment system for exhaust gases reduction in the internal combustion engines [3]. It reduces a nitrogen oxide (NO_x) emissions and used in petrol, gasoline and diesel engines. EGR recirculates a portion of an exhaust gas coming out from engine back to the engine cylinders. As the EGR caused combustion chamber temperatures reduces, the amount of NO_x the combustion generates also gets reduced. It reduces the engine efficiency.

Another after-treatment system for automotive is a Diesel Particulate Filter (DPF) with Selective Catalytic Reduction (SCR) technology [2]. It removes over 90% of particulate matter (PM) from the exhaust gases. But it increases the NO_x level.

The recent innovation is the SRR i.e. Selective Catalytic reduction system in which the Urea Dosing system is used to reduce the NO_x proportion and Particulate matter concentration is reduced in the engine itself.

II. HARDWARE – IN – LOOP SYSTEM DEVELOPMENT

The proposed system is to develop Hardware-in-loop Test Benches for the simulation of sensors and actuators inside DOSER with the help of Load-box User Interface System (LUIS) and its GUI along with the automation of tests using NI TEST STAND. Fig 2 describes the block diagram of the system

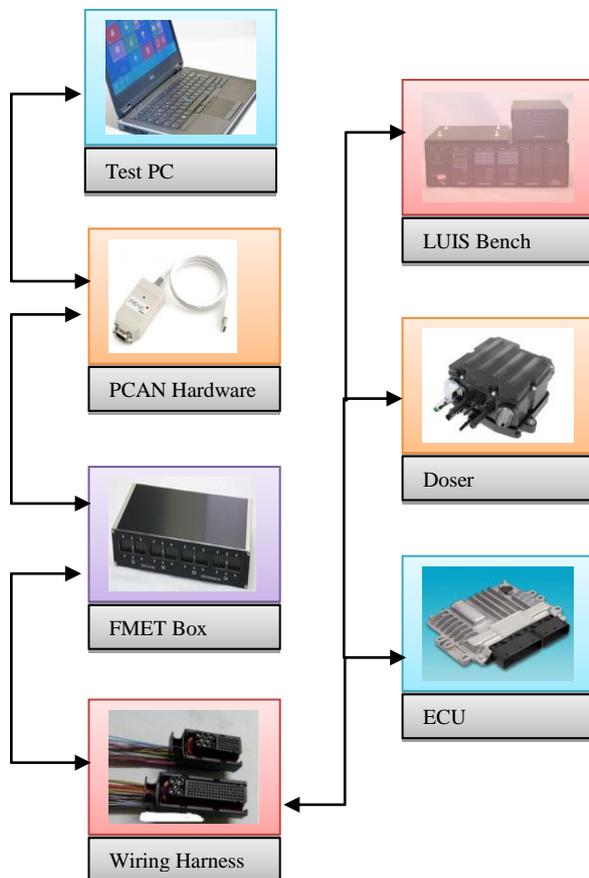


Fig. 2. Block diagram of the system

It consists of Doser, PCAN adapter, ECU, LUIS Bench, FMET box, etc. The sensors and actuators inside the DOSER are controlled through the Electronic Control Unit (ECU). The communication between the ECU and the DOSER unit takes place through the component called PCAN which works on the CAN protocol. The blocks of the Fig. 2 can be elaborated as below –

A. Doser

DOSER is the core part of After-treatment system used as a sprayer to spray urea.. Air-Assisted Urea Dosing System, UA2 is a dosing system that accurately injects a 32.5% solution of urea in water which is also known as Diesel Exhaust Fluid (DEF), into the exhaust stream[4]. The urea mixes with the exhaust gases by utilizing heat from the exhaust and then gets decomposed into ammonia. The ammonia reacts with the SCR catalyst and converts NO_x in the exhaust stream into harmless nitrogen and water.

The dosing system consists of various sensors and actuators inside it as shown in Fig. 3. The sensors are temperature sensor, pressure sensor and mixed air pressure sensor. And actuators are bypass valve, metering valve, Air shut off valve and pump motor.

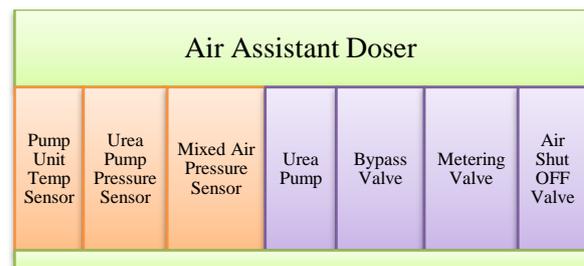


Fig. 3. Block diagram of Air Assistant Doser

B. PCAN Adapter

It is used to make the communication of the ECU, controlling software and DOSER. It works over CAN protocol i.e. J1939 SAE standard for automotive applications. It is a two wire twisted pair protocol. CAN is a multi-master serial bus standard for connecting Electronic Control Units [ECUs]. These ECUs are also known as nodes. The CAN network requires two or more nodes in order to make successful communication. All nodes are connected to each other through a two wire bus. The wires are nominal twisted pair having characteristic impedance of 120Ω.

C. Electronic Control Unit

Electronic Control Unit i.e. ECU is responsible for all the controlling and decision making operations in the system. While testing it detects whether any fault is generated. If the fault is generated, the ECU communicates over the PCAN adapter with the working computer system to show the status of the fault.

D. Load-box User Interface System

The Load Box User Interface System, LUIS, is an engine simulator which is used to facilitate bench top engine control system hardware and software testing[5]. The second generation LUIS system i.e. LUIS Gen2 provides expanded capabilities from the original LUIS.

Fig. 4 shows the standard picture of LUIS box. The Load-box User Interface System (LUIS) is used to simulate the characteristics of the sensors and actuators inside the DOSER with the help of modules of the LUIS bench such as main module, wave maker module, analog module, resistive load module, switch module.



Fig. 4. Load Box User Interface System

E. FMET Box

The FMET box is an electronic relay box. It consists of the electronically operated relays which allow the electrical short and open connection between any two or more pins of the ECU. The relays are operated through the NI teststand software.

III. IMPLEMENTATION AND RESULTS

Fig. 5 shows the complete flow of the system implementation. First step is to understand the conventional set up for the FMET testing and the FMET procedure.

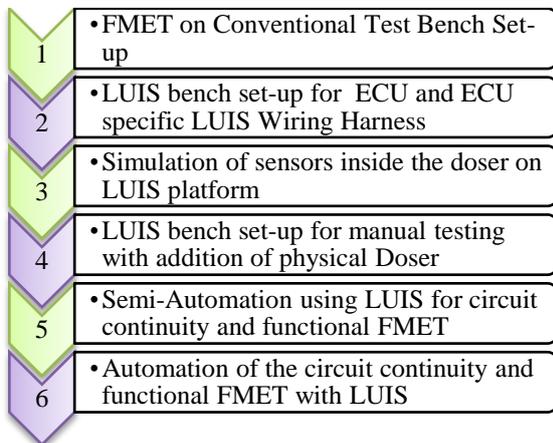


Fig. 5 System implementation flow diagram

The conventional test bench consists of the ECU, Doser, Wiring harness and break out box. The breakout box is just a gateway between the ECU and the Doser. It is used to short or open any pin/s of the ECU or doser. In the second step, the system is set up with LUIS Bench, ECU and ECU specific wiring harness for LUIS Bench. In the third phase the simulation of all the sensors and the required parameters is done on the particular LUIS platform using LUIS GUI. Next step is to add the physical doser in the system because it is required to run the actual doser using LUIS GUI. When the parameter values are changed with the help of simulated sensors, the doser

starts operating. This shows the Doser is successfully implemented in the LUIS system.

The next step is to semi automate the system without help of the FMET box. This step is carried out to check whether the implemented system works properly with the NI Teststand sequence. The normal dosing cycle i.e. purge, prime, dose, prime, purge is carried out with the help of NI test sequence and the doser has responded as per the requirement. The PASS result for the normal dosing operation is witnessed with the help of Fig 6(a) and 6(b).

INITIALIZING THE PARAMETERS FOR NORMAL DOSING					
Verify that the parameter H_EPS_n_UserOverrideSpeedValue	1200	== 1200	+/. 0	Pass	0
Verify that the parameter H_EPS_s_UserOverrideSpeedEnable	1	== 1	+/. 0	Pass	0
Verify that the parameter O_AIM_pc_Urea_TankLvl_Enable	1	== 1	+/. 0	Pass	0
Verify that the parameter O_AIM_trc_Urea_TankT_Enable	1	== 1	+/. 0	Pass	0
GIVING DOSING COMMANDS					
Verify that the parameter O_USM_fm_DosingCmd_Enbl	1	== 1	+/. 0	Pass	0
Verify that the parameter O_USM_fm_DosingCmd_Val	1	== 1	+/. 0	Pass	0

Fig. 6(a) Normal Dosing – ON

Verify that the parameter O_USM_fm_DosingCmd_Enbl	0	== 0	+/. 0	Pass	0
Verify that the parameter O_USM_fm_DosingCmd_Val	0	== 0	+/. 0	Pass	0
Verify that the parameter H_EPS_s_UserOverrideSpeedEnable	0	== 0	+/. 0	Pass	0
Verify that the parameter H_EPS_n_UserOverrideSpeedValue	0	== 0	+/. 0	Pass	0
Verify that the parameter O_AIM_pc_Urea_TankLvl_Enable	0	== 0	+/. 0	Pass	0
Verify that the parameter O_AIM_trc_Urea_TankT_Enable	0	== 0	+/. 0	Pass	0

Fig. 6(b) Normal Dosing – OFF

Then the last phase is complete automation of the system with the help of the electronically controlled FMET Box. This box will turn ON the series of relays so as to short or open the particular pin of the ECU to generate the fault. Again same series of relays is turned OFF to remove the fault. In this manner the complete automation of the failure modes effects tests is implemented.

As a case study temperature sensor shorted to VBATT fault is simulated and removed and the complete test sequence is written in NI Teststand. The algorithm for simulating and removing the Temperature Sensor shorted to VBATT fault is given in Fig. 7. And the PASS results for the fault is witnessed with the help of Fig. 8

The first step is to configure the complete bench set up with the required configuration and calibration file. This is called as total bench configuration. Then next step is to establish the session with the required scripting software tools. Next is initializing the feature test report, monitoring report file. The next is to start the normal dosing, to simulate the fault condition by turning ON the required relay series and to check whether the required fault code is

activated. If the fault code is activated, it will return value 1 and will update the PASS result in feature test report. After the removal of fault the fault is deactivated returning value 2 and again PASS result is reflected in the feature test report as witnessed in Fig 8. The bar graph for the comparison of time required performing FMET on conventional bench and the automated bench is given in Fig. 9.

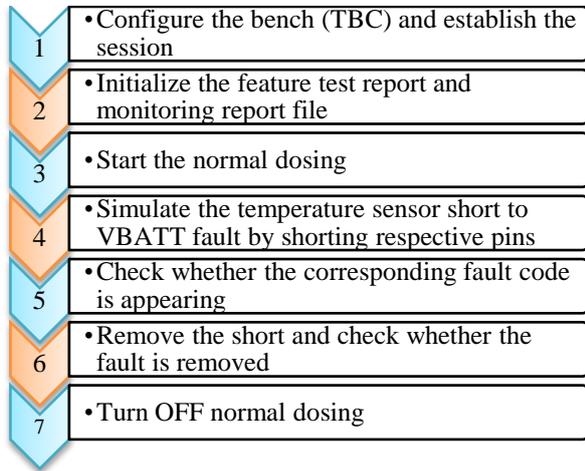


Fig.7. Algorithm for Temperature Sensor Short to VBATT fault

CHECKING FAULT CODE STATUS AFTER MAKING SHORT					
Checking whether Fault Code is appearing	1	==1	+/.0	Pass	0
CHECKING FAULT CODE STATUS AFTER REMOVING SHORT					
Checking whether Fault Code is appearing	2	==2	+/.0	Pass	0

Fig. 8 Activation and deactivation of the fault – result

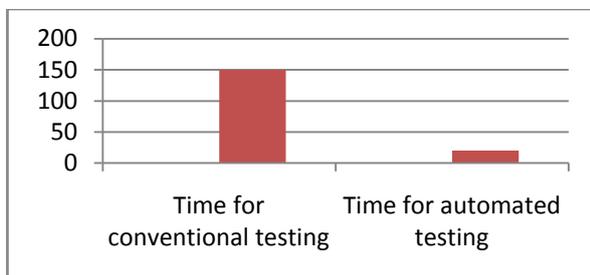


Fig. 9 Comparison between testing time requirements

IV. CONCLUSION

This paper implements the novel testing-time reduction approach in the hardware – in –loop devoted for the testing of the doser i.e. after treatment system developed for the heavy duty, medium duty or light duty

vehicles. The developed HIL automated system articulate the industrial real time emulator. It simulates the required fault condition and removes them according to the testing requirements of the failure modes effects tests. It provides same results as the conventional bench failure modes effects testing in less time.

The test results help in scrutinizing the performance of the doser with various ECUs under tests per the requirement. This automated hardware – in – loop testing performed in the reproducible, controlled and efficient way create the real time environment.

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