HARDWARE – IN – LOOP TEST BENCH DEVELOPMENT AND AUTOMATION FOR FAILURE MODE EFFECTS TEST OF AFTER-TREATMENT SYSTEM

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Abstract- After-treatment system uses urea to treat exhaust gases coming out of automotive vehicles in order to meet the automotive emission regulation, on board diagnostics and to make environment cleaner and safer. A dosing unit called Doser is used to inject the Urea. This system is electronically controlled through an ECU based on inputs & outputs from set of sensors & actuators inside the doser. In order to assess the performance of this control system, circuit continuity and its functions Failure Mode Effect Tests (FMET) are conducted. In the conventional FMET system the tests are simulated and its functionality is assessed by using the normal bench which consists of ECU, Doser and wiring harness. However, a new test bench set up called as Hardware – in – loop test bench can be developed and automated with NI test stand. The hardware in in loop test bench consists of ECU, Load box User Interface System (LUIS), Wiring Harness, FMET box and Doser. This test bench can be used in order to increase the accuracy and to reduce the test time.

Keywords- After-Treatment, Doser, Hardware-in-loop Testing, LUIS and Test Automation.

I. INTRODUCTION

The engines for heavy duty, medium duty and light duty vehicles use very high horsepower engines which emit toxic exhaust gases. These gases are harmful to the environment. There are various norms and regulations for these exhaust gases emission called as emission norms. Hence to meet the emission norms and to make environment cleaner and safer these exhaust gases are reduced to particular level. The dominant exhaust gases from these vehicles are NOx i.e. Oxides of Nitrogen and particulate matters. Particulate matter is also known as particle pollution or PM. It is a complex mixture of extremely small particles and liquid droplets which come out with exhaust gases from the engine. In heavy duty, medium duty and light duty vehicles the particulate matters concentration is reduced within the engine itself making the compromise with increased NOx. After-treatment system is necessary to control the environmental pollution due to emission of NOx from all these vehicles. To reduce the NOx, urea solution is sprayed over the exhaust gases which convert NOx into N2 and H2O (water). Urea solution contains 32.5% of urea and 67.5% of distill water. DOSER is the core part of After-treatment system used as a sprayer to spray urea.

In order to ensure performance and maximize the environmental benefits of this system, an advanced control technology is employed. For excellent performance of dosing system, the fault-free dosers are required. The Doser needs to be calibrated and tested for its robust and error-free operation. Thus the Doser has to undergo rigorous testing in terms of durability, functionality and accuracy. In order to achieve the correct testing, conventional test bench set up was used in early days. In this the actual doser was controlled through Electronic Control Unit (ECU). Each time separate setup of test bench needed for each new testing. This control system gets the inputs from the set of sensors such as temperature sensor, pressure sensor, mixed air pressure sensor etc. The electronic control unit gives the controlling instructions to the output actuators depending on the inputs from the sensors. While performing the testing on the real doser, various damages to the sensors inside the doser have to be faced. Also this process was time consuming, less efficient and prone to manual errors.

The flaws in the conventional testing are overcome by Hardware-in-Loop i.e. HIL system. The HIL Test Bench setup basically consists of an ECU, set of sensors and actuators, DOSER unit and corresponding warehouses. The characteristics of these sensors and actuators are simulated with the help of Load-Box User Interface Systems (LUIS) as a part of Open Loop Test Bench setup. Various tests like Regression tests, Functionality tests and Electrical Circuit Continuity tests can be generated and performed with the help of this Load-Box. Automation of Failure Mode Effects Tests is carried out with the help of NI-TEST STAND.

II. HARDWARE – IN – LOOP SYSTEM DEVELOPMENT FOR FAILURE MODES EFFECTS TESTS

The 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.
2.1 Test PC
All the required software tools are controlled through the test PC. The Calterm software is used to continuously monitor the system while doing the manual testing. The Peak explorer software tool is used to monitor all CAN related activities. The NI Teststand software is used for the automation purpose. The NI test stand software tool directly monitors the parameters from the ECU. Hence while carrying out the testing with complete automation, the Calterm software is not required.

2.2 CAN Hardware
It is used to make the communication of the ECU, controlling software and DOHER. It works over CAN protocol i.e. J1939 SAE standard for automotive applications. It is a two wire twisted pair protocol having characteristic impedance of 120Ω.

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

2.4 Wiring Harness
The wiring harness is a bunch of all the wiring set up used for developing the complete test bench setup. The wiring harness for the complete set up is in two parts. First set of wiring harness is for the LUIS bench and ECM and another set of the harness is for the FMET box and ECM. If the type of the ECM for the complete test bench setup changes then the wiring harness also changes.

2.5 LUIS Bench
The Load Box User Interface System, LUIS is an engine simulator used to facilitate bench top engine control system hardware and software testing. The pictorial view is shown in figure 2. The LUIS Gen2 has a main module that is connected to the PC via USB. Additional modules can be added including Wave maker, Switch, Analog and Resistive Loads to customize the system to fit the user’s specific needs.

Main Module – Main module of the LUIS bench has all the power as well as communication connections. It has various LEDs, Relay LEDs, connectors and test points on the front and rear panel.

Wave maker Module – Wave maker Module supports up to 8 arbitrary waveform outputs with an arbitrary waveform card required for each channel.

Analog Module – The analog outputs are arranged in groups of 4, and each group requires a reference voltage input.

Switch Module – Switch contacts are rated for 1.5A. The internal switch relay commons are rated for 1.5A.

Resistive Load Module – The Resistive Loads Module contains a total of twelve 1k ohm loads and twenty-four 100 ohm loads.

2.6 Doser
The DOSER is the core component used to spray the urea over the exhaust gases from the vehicles. The DOSER comprises of the set of sensors and actuators as Temperature Sensor, Bypass Valve, Metering Valve, Air Shut Off Valve, Urea Pump, Pressure Sensor and mixed air pressure sensor. Out of which the sensor part we can simulate on the LUIS bench but for actuator part the doser is connected. This paper scope involved the automation of the faults related to temperature sensor, Bypass valve and DEF suction line. Hence this part is explained in detail below.

Temperature Sensor – The thermistor is used as a temperature sensor inside the doser and converts it to equivalent voltage. This thermistor is having a negative temperature coefficient. It senses the temperature ranges from -40° to 100° and gives equivalent voltage which ranges from 0 to 5 volts. When the extreme temperatures are sensed it gives the extreme voltages. When the sensor suffers short or open circuit then it reflects the extreme temperature values in the system.

Bypass Valve – It is pressure reducing valve. The term bypass valve refers to any valve installed in a bypass line, and is not used to indicate a particular valve shape or configuration. There is a preloaded spring with the pressure of 550 kPa in the housing of valve. When the DEF pressure inside the doser reaches the threshold pressure of bypass valve, the valve opens and the excess of DEF will be flushed out of the system through transfer line.

2.7 Electronic Control Module
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.
III. IMPLEMENTATION AND RESULTS

This section describes the complete implementation flow, implementation and results for normal dosing cycle, bypass valve stuck open fault as a case study and testing time comparison report between conventional bench testing and automated testing. Figure 4 shows the complete implementation flow of the system right from performing the FMET on the conventional test bench to the automation of the FMET.

3.1. System Implementation flow

**FMET on Conventional Test Bench Setup** – 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. This step in the complete system implementation is carried out to understand the complete testing procedure as it is required to automate the same testing procedure.

**LUIS bench setup for manual testing with addition of physical Doser** – 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. If a particular fault is to be simulated manually, then by using the fault related parameter gauge, the fault should get activated. Then the system is said to be ready for manual testing.

**Automation of the circuit continuity and functional FMET with LUIS** – 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. The NI teststand helps to completely automate the system. The particular fault is simulated with NI test stand and same fault is reflected in the system and same is read by the NI test stand again, then the automation of the fault is said to be completed.

3.2. Automated normal dosing cycle testing

The normal dosing cycle includes Key switch ON, Doser power on, Defrost, Purge, Prime, Dose, prime, purge, and Doser power off operations in the given sequence. And if any of the operation is not completed due to certain error the respective fault code should be detected. Defrost event is explained as the defrosting of the crystalized urea in the doser urea lines and tank. Before priming the bypass valve is kept open for some seconds to remove the residual urea and to relieve the pressure of urea pump. This event is called as purging. Then priming event is to check whether the required pressure is built within the doser. Then the dosing command is given to spray the urea through transfer line.

All the above operations have to be done sequentially in order to test the normal dosing operation. This is implemented with the help of NI LabVIEW and NI TESTSTAND. And the result is recorded in the FMET worksheet called as feature test report. This feature test report is generated automatically with NI TESTSTAND by automating the SQL commands to open and then edit the particular tab in worksheet.

**Simulation of sensors inside the doser on LUIS platform** – In the third phase the simulation of all the sensors and the required parameters is done on the particular LUIS platform using LUIS GUI. Simulation of the sensor is done in order to eliminate the need of actual sensors. In the LUIS environment, the sensor input vs. its equivalent count value is mapped in the interpolation table. The same interpolation table is attached with the particular gauge. Now if the simulated gauge operates as that of the actual sensor, the sensor is said to be successfully simulated in the LUIS environment.
3.3. Bypass valve stuck open FMET automation
The bypass valve is used in the doser to remove the residual urea and to relieve the residual pressure in the urea pump. So if the bypass valve is not working properly the doser will fail to operate in correct manner. In such a case doser will not be able to build any pressure. Hence there is a need to check the functionality of the bypass valve in FMET. Due to all these reasons the functional fault called as the bypass valve stuck open is the critical fault of on board diagnostics.

3.4 Testing time Comparison between conventional and automated testing
The bar graph for the comparison of time required performing FMET on conventional bench and the automated bench is given in Fig. 7.

**REFERENCES**


