RESEARCH ARTICLE

Model Based Simulation of Emission Test Cycles for BS-IV & BS-VI

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ABSTRACT

Engine emissions are result of photochemical reactions during combustion of fuel in engine. These reactions give by-products like CO, CO_2, NO_x and Particulate Matters (P.M.), which are harmful to health and environment [12]. Emission Legislation instituted emission standards to regulate air pollutant emitted from Internal Combustion (I.C.) Engines. As per these standards each engine has to pass through Emission Test Cycles (ETC) before installation. The tests are performed as per European Regulation-2000(BS-IV) or World Harmonised Standards (BS-VI). The emission test cycles are integral part of diesel engine performance tuning and emission certification. Engine development team uses most of its time on test cell to optimize engine's performance and check its consistency with each level of testing. Different engine OEM's invests lots of money and time in developing activities to achieve optimized results. To overcome this problem, it is necessary to work on model based approach to optimize engine testing time at test cell so that it will benefit in terms of time & money. Specified parameters or a range of conditions, such as operating temperature, load, and speed etc. can be used with test cycle to perform this function. This paper explains how this test can be performed with the help of Cummins Engineering, NI-Teststand, NI-Veristand and NI-LabVIEW tools. The objective of this project is to optimize the coefficients for emission test cycles, to predict necessary modification in design, catalytic reduction, etc. from the simulation result as well as to minimize effective time in test cell and avoid unnecessary consumption of fuel in test cell. We have developed a script using NI-Teststand for ESC, ETC, WHSC, WHTC tests as per Europe Union (EU) standards. We have developed a script using NI-Teststand for ESC, ETC, WHSC, WHTC tests as per Europe Union (EU) standards which are tested on Cummins Automated test bench.

Key Words– Diesel Engine, Emission Test Cycles, ESC, ETC, WHSC, WHTC, NI-Teststand, NI-Veristand, NI-LabVIEW, Cummins Engineering Tool, Cummins Automated Test Bench

I.   INTRODUCTION

Diesel engine which is a compressed ignition (C.I.) type engine, where combustion takes place at high temperature and pressure [1]. Diesel Engine usually used as prime mover in all industries due to its high efficient performance. In automotive industries like heavy duty vehicle, diesel engines are widely used. Typically exhaust gas from combustion of diesel contains CO_2 (12%). H_2O (11%), O_2 (9%), N_2 (67%) [3][5]. These content from exhaust normally depends on load on engine. As load on engine increases amount of oxygen (O_2) decreases, Carbon Dioxide (CO_2) and water vapours (H_2O) increases [6]. CO_2 emission from diesel

engine is lower as compared to gasoline engines, but they produce more Nitrogen Oxides (NO$_x$) and Particulate Matters (PM) [8][9]. Because of these major pollutant from emission, the diesel engines must strictly operate as per regulation for PM. This regulation is applied from public transport to marine, agricultural and construction equipment [7]. As per latest European regulation on emissions from diesel engines in passenger cars is based on both particle mass and number, while the mass regulation for heavy-duty diesel engines has been reduced to 0.01 g/kWh, which is only half of the previous regulation (Euro V) [2]. It gives the concerns about the effect of diesel sub-micrometre particle emission on health and environment, like strict implementation of emission standards by Europe Union. In this paper, an alternate option is proposed to perform model based simulation of Emission Test Cycles as per emission standards, which will ultimately reduce the effective time required to perform same tests in test cells as well as it will avoid unnecessary consumption of diesel. The emission test cycles which are performed in test cell by different engine OEM's performs the tests as per European Standards. The test cycle consists of a number of speed and power modes, which cover the typical operating, range of diesel engines. During each mode the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values weighted [10]. For the same test cycle we developed script file in NI-Teststand. The script created is simulated on Cummins Automated test bench which is used to perform closed loop testing. The test performed are European Steady-State Cycle (ESC), European Transient Cycle (ETC), World Harmonised Steady-State Cycle (WHSC), and World Harmonised Transient Cycle (WHTC) [4]. For these tests sequential script is developed which will map the same speed-torque characteristics as it's mapped in test cell. The speed-torque mapping for simulation is validated from the data received from test cell. The result obtained from test model is to be analysed and compared with actual test specification.

II. METHODOLOGY

Figure 1 shows block diagram for Cummins Automated Test bench where, Electronic

Control Module (ECM) is brain of the system which controls actuators and internal combustion engine to obtain optimum performance.
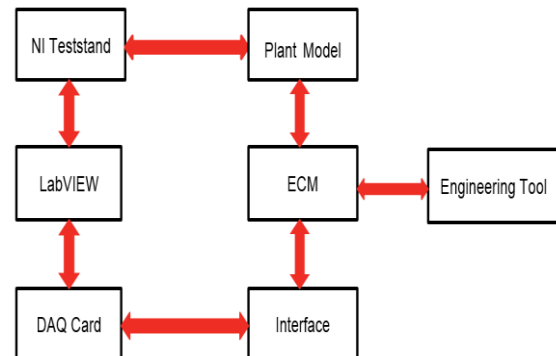

Figure 1. Block Diagram for Cummin**s** Automated Test Bench

(a)   Using this automated test bench we can perform closed loop testing for engine optimization. ECM receives feedback signal for different engine parameters from respective sensors so that ECM can determine error value for that parameter and gives necessary signal to the actuator to get optimum performance from engine. The Plant model is nothing but engine model from which we receives signal for each parameter and further control command is given by ECM. Here we used NI Teststand tool to simplify the automation of test and validation of system. In NI Teststand we can develop, manage and execute desired test sequence. We developed script in NI Teststand such a way that it can be used for all for tests i.e. ESC, ETC, WHSC and WHTC. The test profile is created in excel sheet as per standard which includes actual speed-torque calculations and mode length for different test cycles. While creating script in NI Teststand we can log the data whichever is necessary as per our requirement. Before executing test script we need to configure test bench with necessary engineering files for respective engine model. After configuring test bench we can load the engine model with the help of NI LabVIEW tool. LabVIEW is interfaced with ECM so that using virtual instrument we can observe or command desired parameters. The Cummins Engineering Tool is used to upload or download engineering files for different engine configurations. Also we can read and write parameters with help of this engineering tool. A

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sensor converts a physical quantity into a measurable electrical quantity, such as voltage or current. Based on the signals in our application, we used DAQ cards to measure, generate analog and digital signal. The ECM is connected with remote terminal computer by means of SAE J-1939 communication standard

III.   EMISSION TEST CYCLES

The boundary condition we need to maintain while testing to get optimized result compared to test cell results. The boundary conditions are given in Table 1,The above boundary condition parameters can be set using NI LabVIEW as we can access model parameters from this tool only.

Table 1. Boundary Conditions for testing

Parameter Name	Parameter Value
Intake Manifold Temp located on engine manifold	50 +/- 2 deg C
CAC delta P or Depression	13.5 +/- 1 kPa
Inlet Restrictions or Comp inlet press	-15 +/- 1 inH2O
Exhaust Restrictions	20 +/- kPa
Inlet Temperature	25 +/- 2 deg C or 77 +/- 3.6 deg F
Relative Humidity	45 % +/- 2
NTP Pressure	100 kPa
NTP Exhaust Plenum Pressure	1000 mbar
Fuel Inlet Temperature	38 +/- 1 deg C
Coolant Out Temp	88 +/- 1 deg C

A.   *European Steady-State Cycle(ESC) Test:* In this test, it consists 13 steady-state modes where engine run at 3 different speeds defined by engine manufacturer as A, B and C with different load value for definite interval of time in sequential manner. The engine is operated in prescribed time in each mode where change speed from one mode to another in 20 sec duration. The tolerance value for set speed value is ±50 RPM and torque value should be held within ±2% of maximum torque for respective speed [2]. The test is carried out at three engine speeds and idle. At each of the three speeds, emissions are measured at 25%, 50%, 75% and 100 % loads. To ensure that there are no abnormal operating conditions which could result in

abnormally high emissions, testing agency is authorized to select three more modes as indicated. In this way engine runs through the entire fuel/air ratios defined by the engine fuel management system. Thus, smoke emission from the diesel engines is measured for the entire range of fuel delivery i.e. fuel-air ratios. Peak smokes emissions are compared with the permits as specified in the standards

The Engine Speed A, B, C shall be calculated as,

- Speed A = n_{lo} + 25% $(n_{hi} - n_{lo})$
- Speed B = n_{lo} + 50% $(n_{hi} - n_{lo})$
- Speed C = n_{lo} + 75% $(n_{hi} - n_{lo})$

Where, n_{lo} = Speed at 70 % of declared net power

n_{hi} = Speed at 50% of declared net power

The engine torque shall be calculated as,

Actual Torque (A, B, C)

$$= \frac{\% \text{ Torque} * \text{Maximum Torque(A,B,C)}}{100}$$

The total time required to run this test is 1680 sec. where 100% load is given at mode 2, 8 and 10 only as European Test Standards.

B.   *European Transient Cycle (ETC) Test:* This transient test consists second by second 1800 transient modes with different speed-torque values. Similar to ESC test, the test profile is created with speed-torque target values. The data collected on different road types from which the cycle was derived from i.e., highway, urban and rural roads, under varying traffic density, road gradients and distance between stopping points. For different types of heavy duty vehicles like trucks, buses and city buses the data were collected. The normalized figures are integrated in three sub-cycles of 10 minutes each. To set the emission limits the test cycle for three sub-parts are run separately to measure emissions and further combined using weighing factor. In this test, engine run for second by second sequence of 1800 transient modes. The speed-torque for ETC test shall be denormalized using the following equation:

Actual Speed= $\frac{\% Speed(n_{ref} - n_{idle})}{100} + n_{idle}$

n_{ref} = n_{lo} + 95 %*$(n_{hi} - n_{lo})$

Actual Torque = $\frac{\% torque * max.torque}{100}$

C.   *World Harmonised Steady-State Cycle (WHSC) Test:*

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WHSC consists of a 13-modes of normalized speed and load values which is to be converted into the actual values for the different engines under test based on the respective engine-mapping curve. The engine must be operated for the prescribed time in every mode, whereas engine speed and torque shall be changed linearly within 20±1 seconds. To validate this test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test. The operating engine speed for this test is idle, 25%, 35%, 45%, 55%, 75% and torque is similar to ESC test as 25%, 50%, 75% and 100%.

The speed shall be denormalized using the following equation:

$$Actal\ Speed = \frac{\left(n_{norm} \times \left(0.45 \times n_{lo} + 0.45 \times n_{pref} + 0.1 \times n_{hi} - n_{idle}\right) \times 2.0327\right)}{100} + n_{idle}$$

$$Actual\ Torque = \frac{\%\ Torque * Max.Torque}{100}$$

Where,

n_{pref} = is the engine speed where the max. Torque integral is 51 per cent of the whole integral.

D. *World Harmonised Transient Cycle (WHTC) Test:* Transient test is a sequence of second by second operating engine at normalized speed and torque values. In order to run this test, normalized speed and torque shall be converted into actual values for different engines under the test which is based on its engine-mapping curve. By converting normalized speed and torque value to actual, one can develop a test cycle profile in excel sheet and run in automated script. During test running necessary parameter are recorded. The regression analysis between desired and actual speed, torque and power values is conducted after completion of the test. The actual speed torque calculation for this test is same WHSC test.

IV.   IMPLEMENTATION AND RESULT

Figure 2. Shows flowchart algorithm for all four emission test cycles. In which first step is to configure and establish the test session in the automated test bench with the help of NI-Teststand and we can flash the configuration and calibration files in ECM with the help of Cummins Engineering Tool. During configuring the test bench we load engine model which is to be tested with the help of NI-LabVIEW. Once the bench setup is done second

step is implemented where feature test report is initialized in which all the details of test like test run time, test name, errors, etc.is recorded. In third step the necessary boundary conditions are applied to the test bench given in Table 1. After setting the boundary condition we can start monitoring parameters as per requirement in which we can monitor engineering as well as model parameters. The test profile created for the above four tests can be called in sequence and run as per standard. As soon as we done with test cycle run we need to stop the test cycle and stop monitoring the parameters which is done in step sixth and seventh. The cleanup part for the test is done in step 8, 9, 10 and 11 where we need to restore test bench, close the test report, erase all the setup changes and set the engine to idle speed respectively so that we can perform next test on the bench which may be same or different.

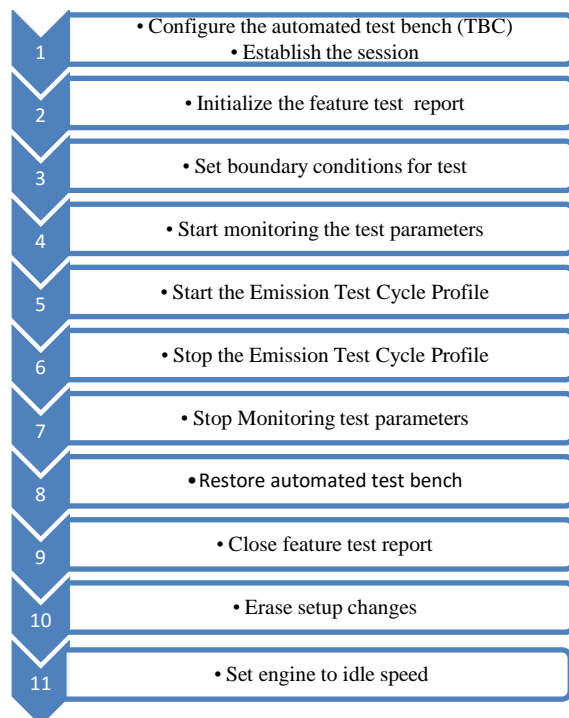|	
1	• Configure the automated test bench (TBC) • Establish the session
2	• Initialize the feature test report
3	• Set boundary conditions for test
4	• Start monitoring the test parameters
5	• Start the Emission Test Cycle Profile
6	• Stop the Emission Test Cycle Profile
7	• Stop Monitoring test parameters
8	• Restore automated test bench
9	• Close feature test report
10	• Erase setup changes
11	• Set engine to idle speed

Figure 2. Algorithm for Emission Test Cycles

The main result is that the implemented method gives optimum speed-torque characteristics, from the simulation result we can observe that speed-torque characteristics we obtained is almost same as expected result values.
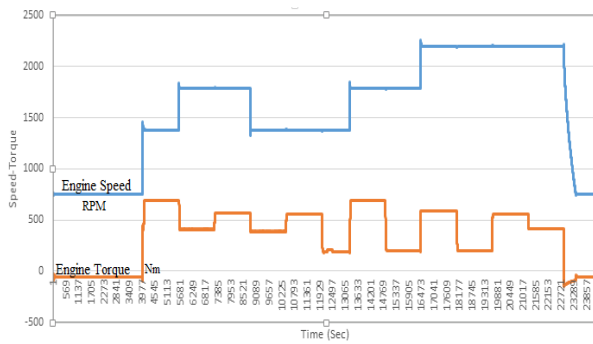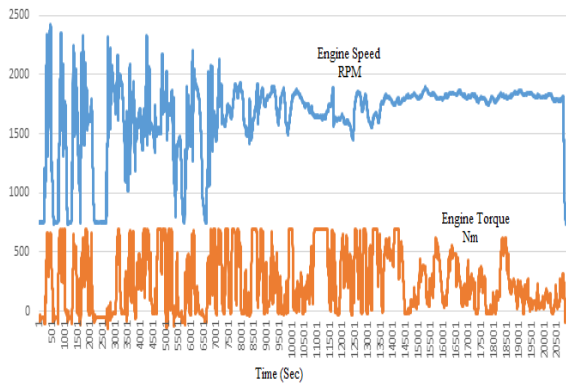
Figure 3. ESC Test
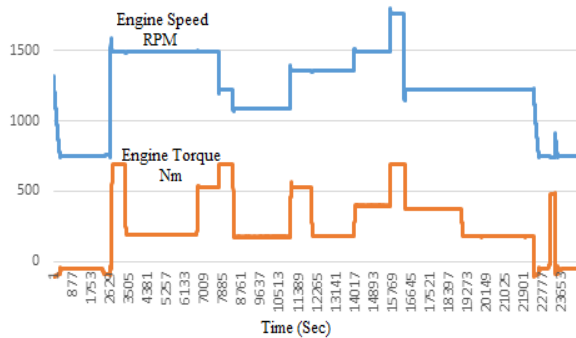

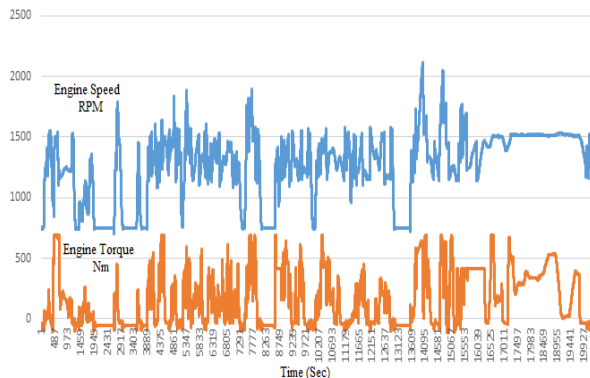Figure 4. ETC Test

Figure 5. WHSC Test

Figure 6. WHTC Test

CONCLUSION

From the obtained simulation result and expected result comparison we can conclude that with the help of simulation we can obtain optimal speed-torque characteristic as expected, also using simulation one can perform emission test cycle as per European Standards to meet the desired emission regulation requirement.

FUTURE SCOPE

This simulation test script has been developed considering Engine model only. In future it will be interesting to see how it works with emission model working in sync with engine model. This will help us to understand specific duty cycle operation vis-à-vis to actual operation cycle.

ACKONOWLEDGEMENT

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