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Optimization of Model-based calibration strategy for development of Diesel

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ABSTRACT

Engine performance, fuel economy and emissions are the major area of development in the automotive sector. With the development in these areas number of control parameters and new subsystems are introduced to the engine which in turn leads to increase in Degrees of freedom. Degree of freedom has to be minimum in number to give efficient results for calibration. As the new control parameters and subsystems are introduced number of degrees of freedom is also increased thus giving the inefficient calibration results. This paper represents use of Model-based Calibration Toolbox in MATLAB/Simulink for engine calibration. Model-based calibration is a method that uses Design of Experiments (DoE), statistical modelling and optimization techniques to efficiently produce high quality calibrations for engines.

***Keywords*— Model-based Calibration, Design of experiments**

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I. INTRODUCTION

To improve the fuel economy, performance parameters and emissions automotive industries are introducing more and more subsystems. These newly introduced subsystems give rise to number of degrees of freedom. Thus causing inefficiency in the previously used method for testing and calibration of engine. This creates a necessity for finding an ultimate substitute for this problem. Earlier engine testing was done by Hardware-in-loop(HIL) method where the engine was connected in the loop for testing. Test data was taken from the experimental test bed obtained from dynamometer, sensor and actuator readings. This data obtained is offline and thus any optimization to be made is impossible. MATLAB/Simulink provides Model-based calibration Toolbox for carrying out engine calibration. Model-based calibration is a method that uses modern Design of Experiments (DoE), statistical modelling and optimization techniques to efficiently produce high quality calibrations for engines. In this calibration approach engine is monitored and controlled by Electronic control unit (ECU) with the coordination of sensors and actuators. The test data obtained is sorted into Design of experiments as per required inputs for the variations in respective responses. In model-based calibration a design of experiments (DoE) is first performed to generate a matrix of engine test factors. Then engine test and measurement are carried out at these points. The number of engine test points should be minimal but still sufficient for obtaining data to create a statistical model that provides enough fidelity in describing the engine responses to variations in the factors. This statistical model is then used for the determination of optimum control parameters of the engine. Once the test plan, design of experiment and responses are fixed it is exported to Calibration Generation CAGE browser part of the Model-Based Calibration Toolbox to calibrate lookup tables using models and data. Data can be trade off competing objectives, and validate calibrations against data.

I. PREPARATION OF LAYOUT

Given Layout consists of a 55kW project diesel engine with high pressure EGR loop is used for the present work. The engine is setup as shown in the below diagram. All the temperature and pressure sensors are calibrated before installing at respective location. The mass air flow, fuel flow and coolant flow sensors are installed to measure air, fuel and

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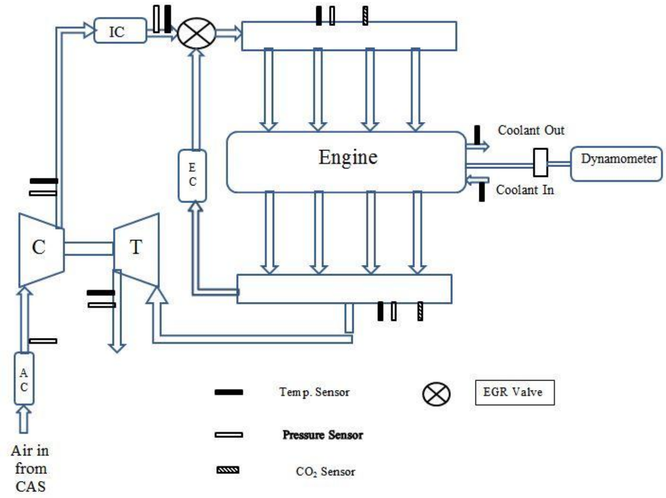

Fig.1. Schematic layout of Engine setup

coolant flow respectively. The coolant flow sensor is positioned at the outlet path of the coolant system. The engine specifications are as follows:

Table.1. Engine Specification

Sr. No.	Specifications	Value
1	No. of cylinders	4
2	Charging	Turbo-charged inter-cooled
3	EGR system	High pressure loop system
4	Displacement	3.0 L
5	Fueling	CRDI

II. THEORY

A. Model-based calibration:

Model-based calibration is a method that uses modern Design of Experiments (DoE), statistical modelling and optimization techniques to efficiently produce high quality calibrations for engines. This approach has several inherent benefits. On the one hand, users are able to work in their familiar calibration environment. On the other hand, the exchange of measurement and calibration data between individual development steps and the final production calibration is seamless and entirely transition-free. This not only simplifies the precalibration of ECU functions but also facilitates – in one and the same Inca environment – a direct comparison of the behavior of functions in the ECU, the prototype, and the function model. The Model-Based Calibration Toolbox (MBC) was used to generate the design of experiments and develop mathematical models to fit to the data. The model accuracy was then analysed using validation data collected. The MBC Toolbox is used to define a test plan, fit statistical models, and generate calibrations. The calibrations were used for feed-forward lookup tables in the engine control strategy.

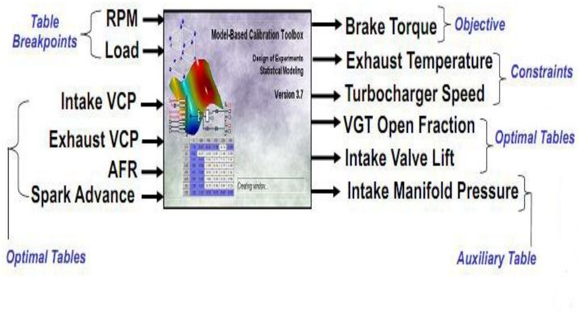

Fig.2.Model configuration for 2.2 L engine

B. Design of Experiment:

Design of experiments (DoE) for an advanced engine is a non-trivial task due all of the complex interactions and constraints. All the test bed data has to be sorted and given as input data to model browser in model-based calibration toolbox and appropriate global inputs and local input data is to be fixed. Test plan is to be decided and responses are to be identified.

C. Calibration Generation (CAGE):

CAGE browser part of the Model-Based Calibration Toolbox is used to calibrate lookup tables using models and data. Trade off can be done competing objectives, and validate calibrations against data. If the calibration model met all error criteria, it is implemented into the Calibration Generation Toolbox (CAGE). The CAGE Toolbox is used to produce optimal fits of calibration data.

D. System flow chart:

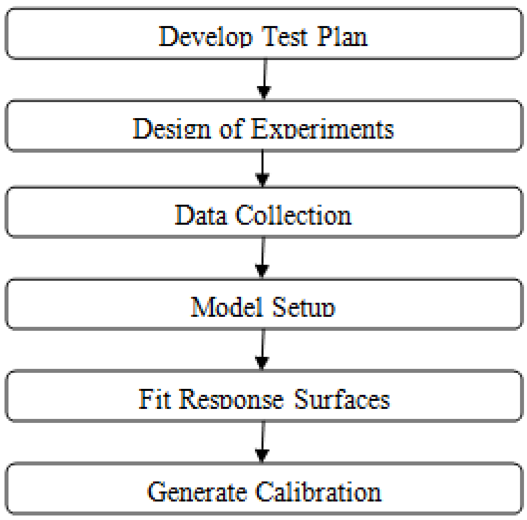

Fig.
3.Flowchart of the MBC process

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III. MODELLING

A. *Developing a Test Plan and Inputting Data:*

To begin the MBC process, a test plan is developed. The organization begins with the test inputs, followed by the type of model for the calibration, and lastly the response surface. The inputs for this test plan are engine speed, start of injection, fuel quantity per injection, fuel pressure, VGT rack position and EGR valve position The type of test plan used for this project is a Two-Stage Global test plan. Two-Stage test plan is offered, which would be developing a system with multiple dependencies. Once the inputs are established, the design of experiments is set up. The MBC Toolbox has a design tool to aid in setting up the DoE. .

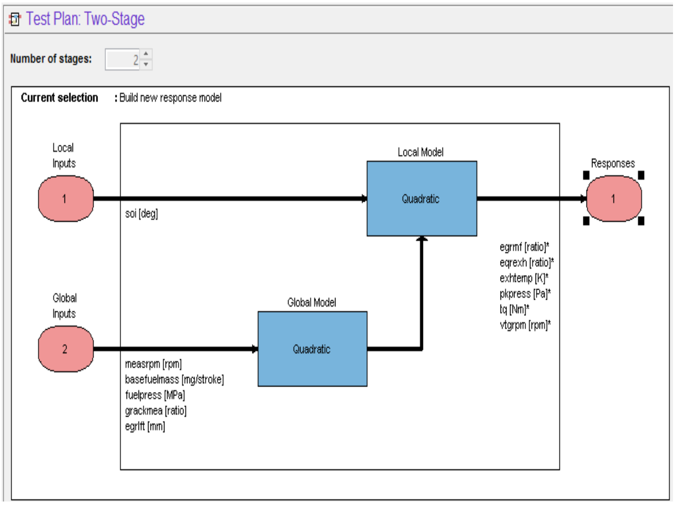

Fig.4.Test plan developer in MBC Toolbox

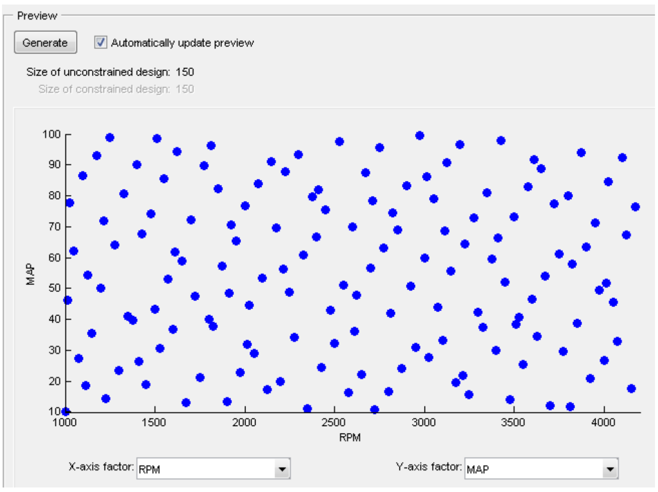

Fig.5.DoE editor in MBC Toolbox

After the DoE is set up and the data is collected and sorted, the data is be imported to the MBC Toolbox via the data editor. The data editor displays test data in table and graphical format to easily check the validity of test results. The display variables can be changed quickly, which reduces the amount of time spent writing intermediate plotting scripts.

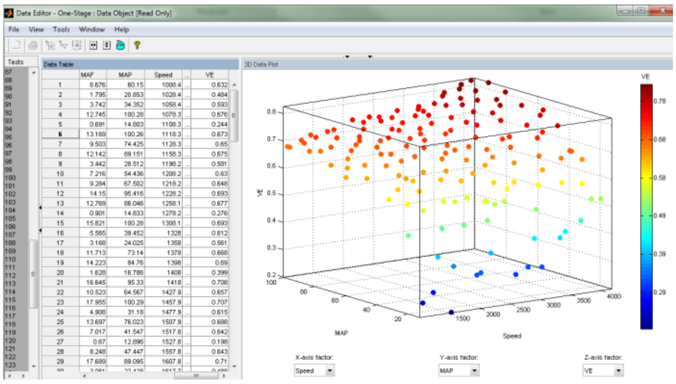

Fig.6.Data editor in MBC Toolbox

B. *Selecting and Building Models to Fit Response Surfaces:*

Once the data is imported and checked, response surfaces can be fit for calibration for calibration development. Models are used for calibration, rather than the direct data, because it is important to understand the system in between data points. This helps avoid excess interpolation that can potentially be error prone. To begin this process, the type of model must be selected for the response surface fitting. The types of models offered by the MBC Toolbox are the following:

a. Linear Models
b. Multi-Linear Models
c. Radial Basis Function (RBF)
d. Neural Network
e. Transient
f. Interpolating RBF

The MBC Toolbox aids in fitting models to the data set. By offering built-in models, the calibrator does not need to write extensive script files for data processing. This helps save time and allows one to study many different models quicker.

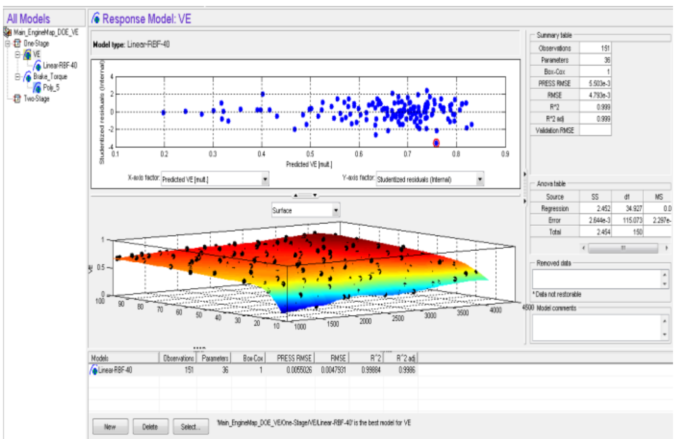

Fig.7.Response model browser in MBC Toolbox

The Response model browser is next used to assess the quality of the model developed. It displays the model fit

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statistics numerically and graphically, as well as, the response surface describing the data.

B. *Generating Calibrations:*

Using the MBC Toolbox, a response surface was fit to characterize the input-output relationship. The CAGE Toolbox is used specifically for generating lookup table calibrations. CAGE provides a user-friendly way of implementing table bounds, tradeoffs, and optimizing calibrations for embedded control design. Then variable definitions should be setup in the variable dictionary feature. From the variable list and model, lookup tables can begin to be made in the tables feature. In the table feature, the refinement of the lookup tables must be selected. The lookup tables can then be improved in the optimization feature. The optimization functionality is most useful in multiple degree of freedom systems, where relationships are not easily understood.

IV. ANALYSIS AND RESULTS

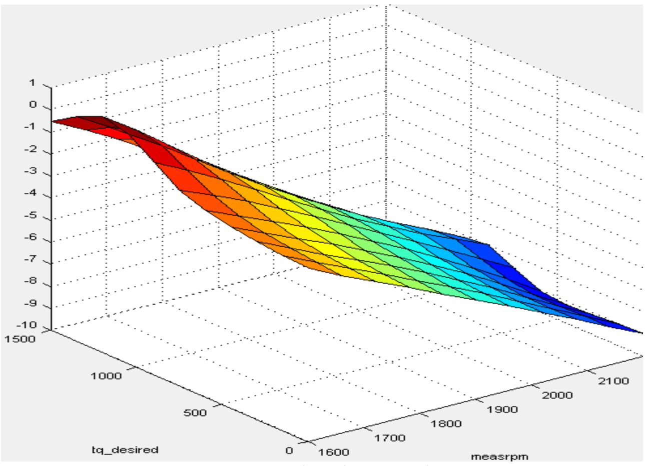
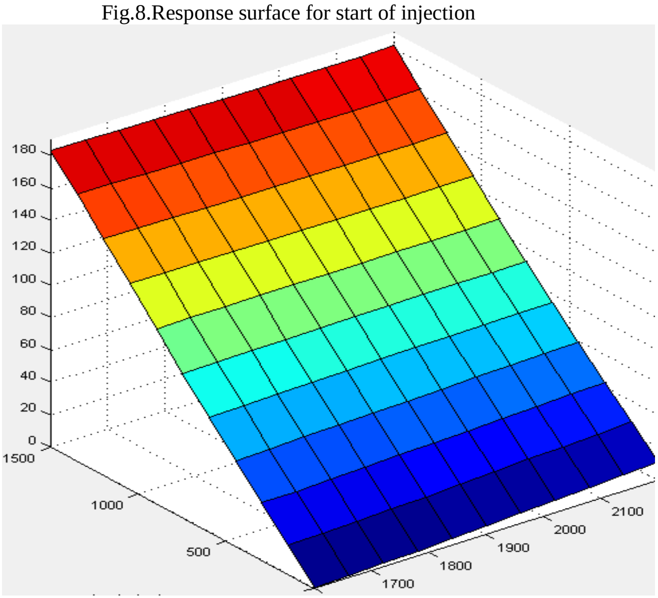


Fig.8.Response surface for start of injection



II.

Fig.9.Response surface for base fuel mass

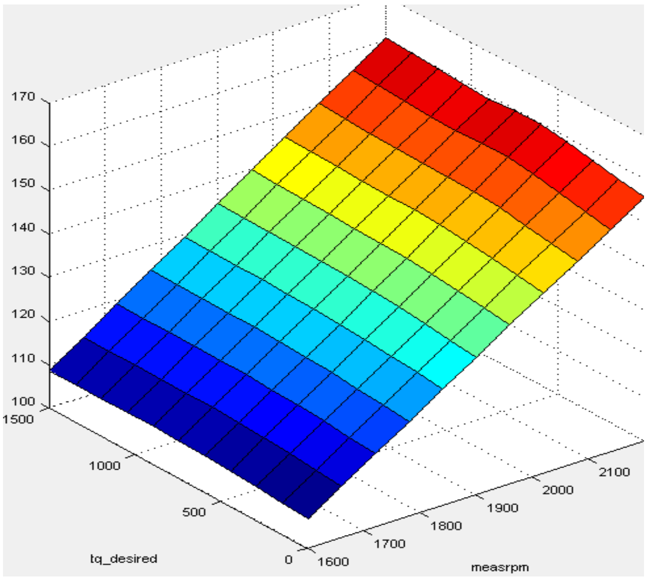
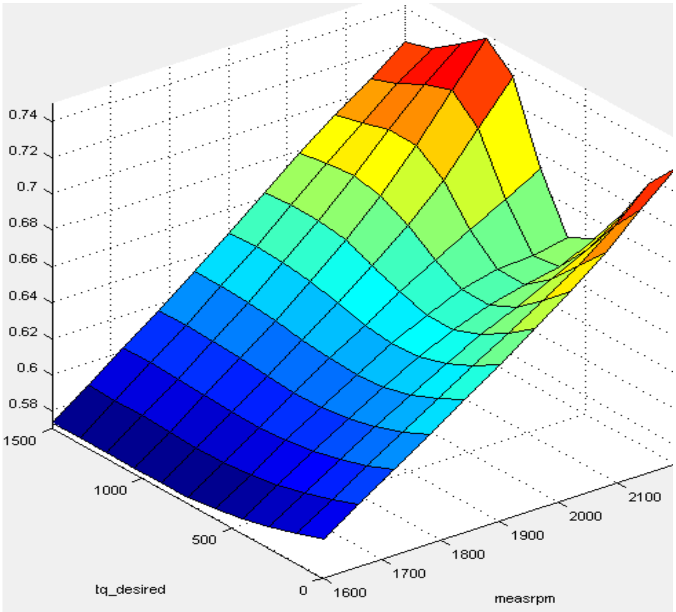


Fig.10.Response surface for fuel pressure

III.



IV.

Fig.11.Response surface for VGT rack position

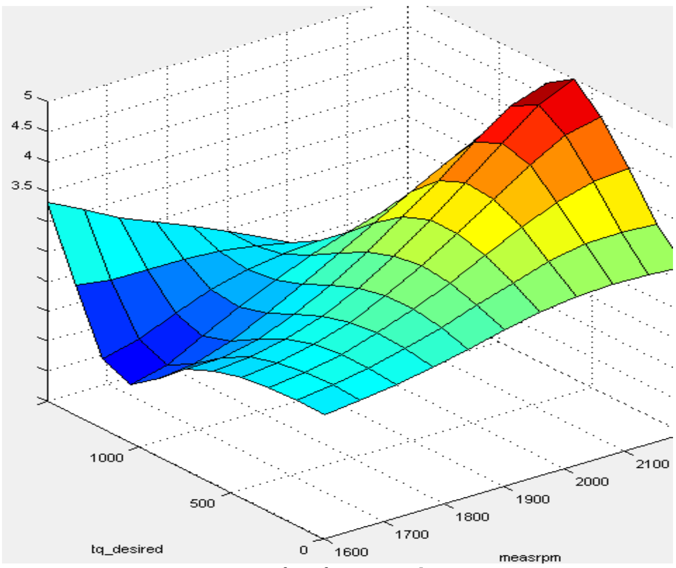


Fig.12.Response surface for EGR valve position

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V. V. CONCLUSIONS

The new features in Model-Based Calibration Toolbox in R20013a have been highlighted. These new features offer large improvements in usability over previous implementations of multimodels. A model-based calibration of start of injection, fuel quantity per injection, fuel pressure, VGT rack position and EGR valve position is carried out for a diesel engine using MATLAB/Simulink. The application
indicates that MATLAB/Simulink automated engine control and measurement system provide effective methods for implementing model-based calibration.

VI. ACKNOWLEDGMENT

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