Modern Applied Science
www.ccsenet.org/journal.html
Vol. 3, No. 3
March 2009

An Experimental Approach for Engine Mapping

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Abstract

Both collecting data and constructing of a diesel engine's specific fuel consumption model by two-stage modeling approach is investigated in this study. The cam angle is swept from minimum to maximum for different engine speed and torque values and, the specific fuel consumption at these points are measured at an engine test bench in a workshop. The different specific fuel consumption models are created by using the collected data and, the best model among these models is chosen by the help of statistical parameters

Keywords: Engine mapping, Two-stage modelling, Specific fuel consumption

1. Introduction

Engine mapping is the modeling engine behaviors as a function of engine's adjustable parameters. The main objective of engine mapping is optimizing engine parameters due to desired restrictions, which is called model-based calibration. The benefits of the calibration methodologies utilising a model based approach both enable the calibration engineer to visually evaluate the parameter interactions in a multidimensional space and also give the ability to evaluate the drive/emissions compromise with no additional testing (Guerrier M., Cawsey P. 2004).

The objective of this study is describing experimental approach for two-stage engine mapping and constructing the specific fuel consumption model of a diesel engine. The two-stage modelling method is supported in model-based calibration toolbox by MATLAB.

2. Two-Stage Modelling

The way of collecting data for the two-stage modelling is to fix engine speed, and torque within each test and sweep cam angle from minimum to maximum value. This type of data collection has two sources of variation. The first source of variation is within each cam angle sweep, when the engine speed and torque are held constant, and it is called local. The second source of variation is between the cam angle sweeps when the engine speed, and torque change, and this is called global. The specification of the diesel engine used for this study is shown in Table-1

Two-stage modelling estimates the local and global responses separately by fitting local and global models in two stages. A local model is fitted to each cam angle sweep independently, and the results of these local models are used to fit global model across all the global variables. Once the global model has been estimated, it can be used to estimate the local models' parameters for any engine speed, and torque values (Model Browser User's Guide).

The least square method is used to estimate the coefficients of both local and global models. This method chooses the coefficients of the models so that the sum of squares of the errors is minimized (Kazan R, Taymaz I, Gokce M).

3. Experimental Study

The data used in this study is collected at a test bench in a workshop. The engine test bench and the screen of control console are shown in Fig-1 and Fig-2 respectively

The different values for both engine speed and torque are adjusted manually by the help of the control console, and the cam angle is adjusted mechanically by using the marks on the flywheel of the engine as shown in Fig-3.

After each cam angle changes, the fuel pump's injection time must be also adjusted. This adjustment is done also mechanically as shown in Fig-4.

The different combinations of engine speed and torque are tried for each cam angle sweeps, and the specific fuel consumption is measured for each measurement point. The measurement set up is shown in Table-2.

4. Modelling the Engine

After the data is collected, the data is transformed in to excel format to be used in the toolbox. The algorithm used in two-stage modeling approach is shown in Fig-5.

The global inputs are engine speed and torque whereas local input is cam angle, which is swept from maximum to minimum values, and the response is the specific fuel consumption.

There are different types of functions for both local and global model that can be chosen by the engineer. Once the local model type is chosen, the curve is fitted for each cam sweep as shown in Fig-6.

The dark points are the measured specific fuel consumption for the cam angles, and the curve is the fitted curve for quadratic function.

The model definition is given for each local model, which is given below for test no:7;

$$spefuelcon = 897.737 + 2.793 \times C - 51.388 \times C^2 \tag{1}$$

where,

$spefuelcon$: specific fuel consumption

C: cam angle.

The local model definition is evaluated for each cam sweep, which is 90 for this study. This is the first step of two-stage modeling. Afterwards, the global coefficient of the model is evaluated by using the coefficients of each model, which is the second step of two-stage modeling.

At the end of modeling, the equation for specific fuel consumption is evaluated as shown below;

$$spefuelcon = a1 + a2 \times C + a3 \times C^2 \tag{2}$$

where $a1, a2,$ and $a3$ are calculated in terms of engine speed and torque. In other terms, first $a1, a2,$ and $a3$ shall be calculated for any engine speed and torque, then the specific fuel consumption can be evaluated for any cam angle by using Eq. (2).

The more detailed explanation of two-stage engine mapping for CO emission response is presented in Ref (Tabak S, 2007) which is very similar to specific fuel consumption model.

The different model types are tried for specific fuel consumption response and the best model among these models is chosen by using the statistic parameters given by the toolbox, which are root mean squared error (RMSE) and predicted sum of squares (PRESS) RMSE.

RMSE indicates how well the curve is fitted to the measurement points, whereas PRESSS RMSE shows how well the model evaluates the measurement model if it is included during the measurement.

The calculated statistical parameters for different models are shown in Table-3.

The best model is chosen as model "D" in Table-3, because it has the lowest RMSE and PRESS RMSE values.

The 3-D view of the best chosen model is displayed in Fig-7.

5. Results and Discussions

The most benefit of two-stage modelling is the ability to choose different function types for local and global models, which decreases the model's RMSE value, whereas one function type can be chosen during current one-stage modelling.

The outliers are displayed during modelling, and the engineer can remove these outliers during modelling to improve the models (Kozan R., Gokce M. 2009). However this must be done very carefully, because the removed data can be very specific character of the engine.

Two-stage engine mapping is the first step of model-based calibration. Since the model is created, this model can be used in CAGE browser of the toolbox to optimize the cam angles for desired objectives.

References

Guerrier M.,Cawsey P., (2004). "The Development of Model Based Methodologies for Gasoline IC Engine Calibration", SAE Technical Paper Series, 2004-01-1446.

Kazan R, Taymaz I, Gokce M, "The Comparison of Two-Stage and One-Stage Engine Mapping", European Journal of Scientific Research, Vol 20, pp 24-36

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Model Browser User's Guide, Model-Based Calibration Toolbox, MATLAB

Tabak S, "Diesel Engine Calibration Approach with Two-Stage Modelling Approach", MSc Thesis, Sakarya University, May 2007.

Table 1. The specification of the diesel engine

Cylinder Number	10
Cylinder Inner Diameter	165 mm
Stroke	175 mm
Compression Ratio	1:18 – 1:19.5
Maximum Power	2200 rpm, 610 KW (830 HP)
Maximum Engine Speed	2400 rpm without load

Table 2. The measurement set up

Cam Angle (^{o})	**Torque (Nm)**	**Speed (rpm)**
-10, -8, -6, -4, -2, 2, 4, 6, 8, 10	200	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	400	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	600	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	800	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	1000	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	1200	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	1400	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	1600	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	1800	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480
	2000	850, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2480

Table 3. The statistics of the investigated models

Model	Local Model	Global Model	Local RMSE	Two-stage RMSE	PRESS RMSE
A	Quadratic	Quadratic	29.99	66.11	72.78
B	Cubic	Quadratic	29.99	49.26	55.28
C	Cubic	Cubic	31.23	42.20	48.37
D	Cubic	Poly_4	31.23	34.65	39.84

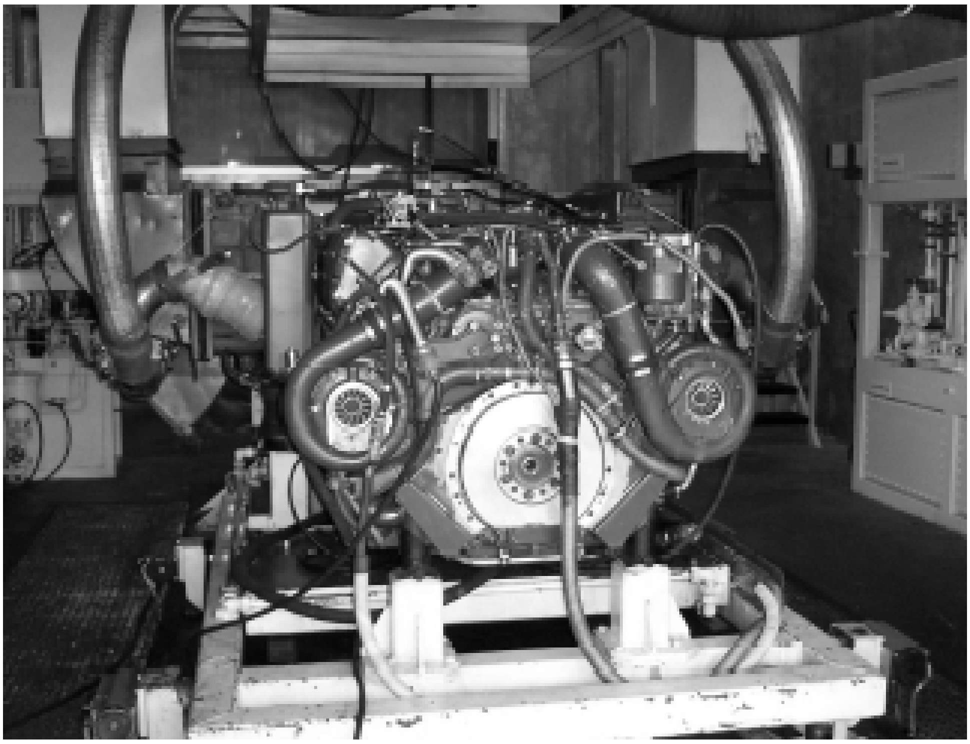

Figure 1.The engine test bench [4]

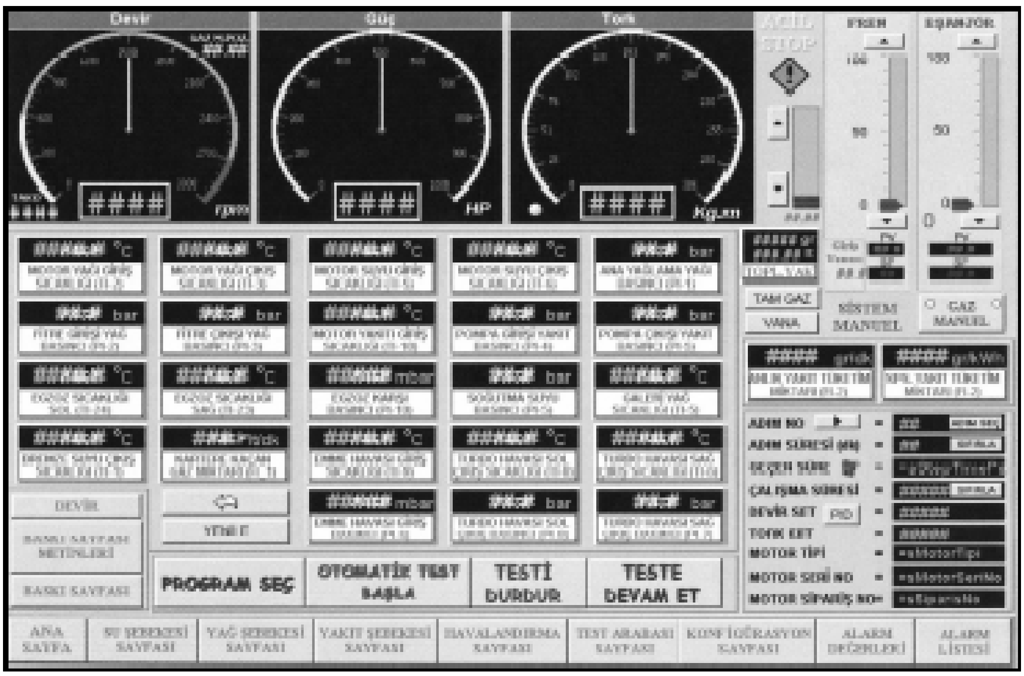

Figure 2. The screen of control console [4]

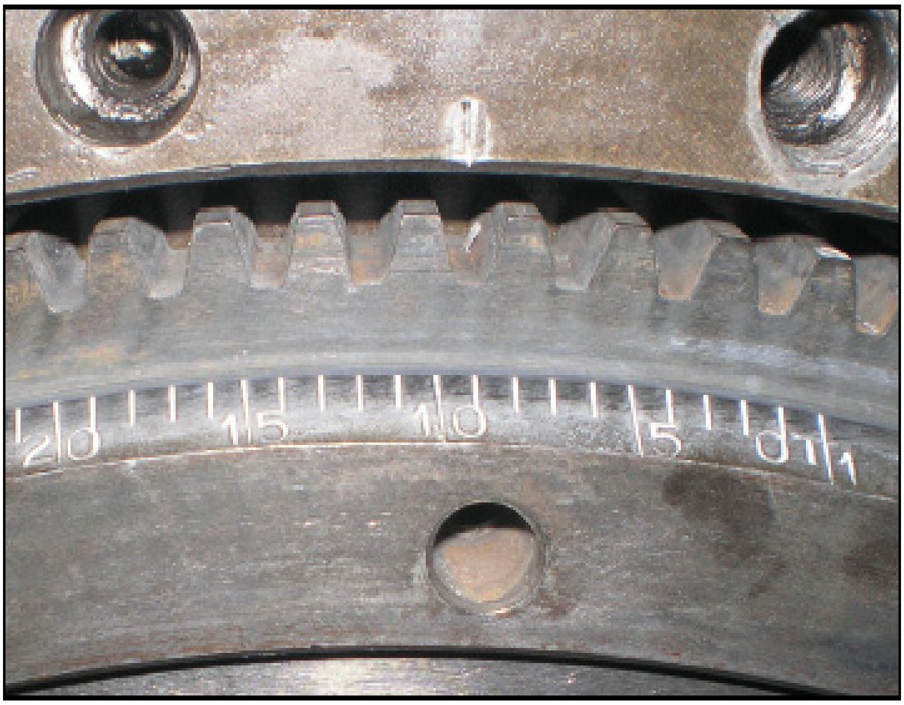

Figure 3.The cam angle degree marks on flywheel [4]

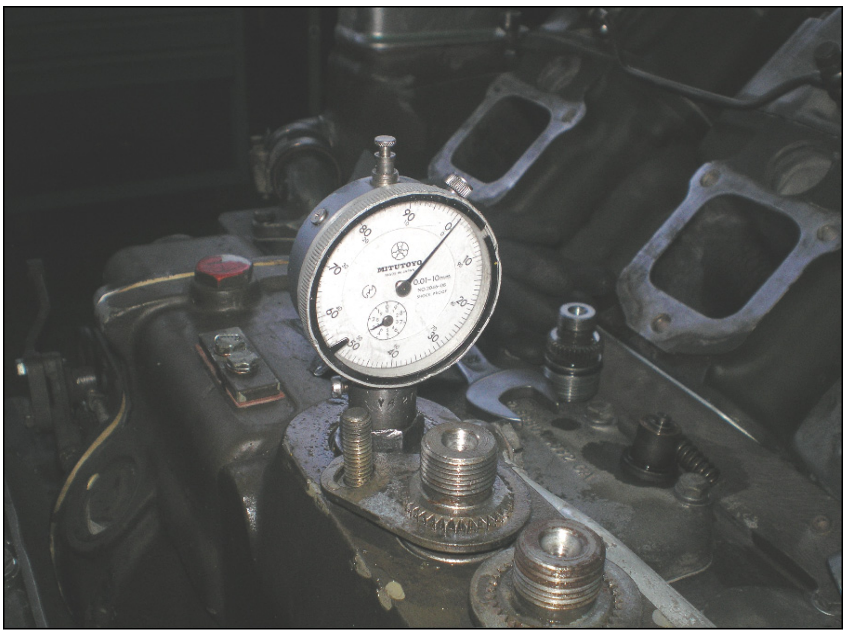

Figure 4. The mechanical adjustment of fuel pump [4]

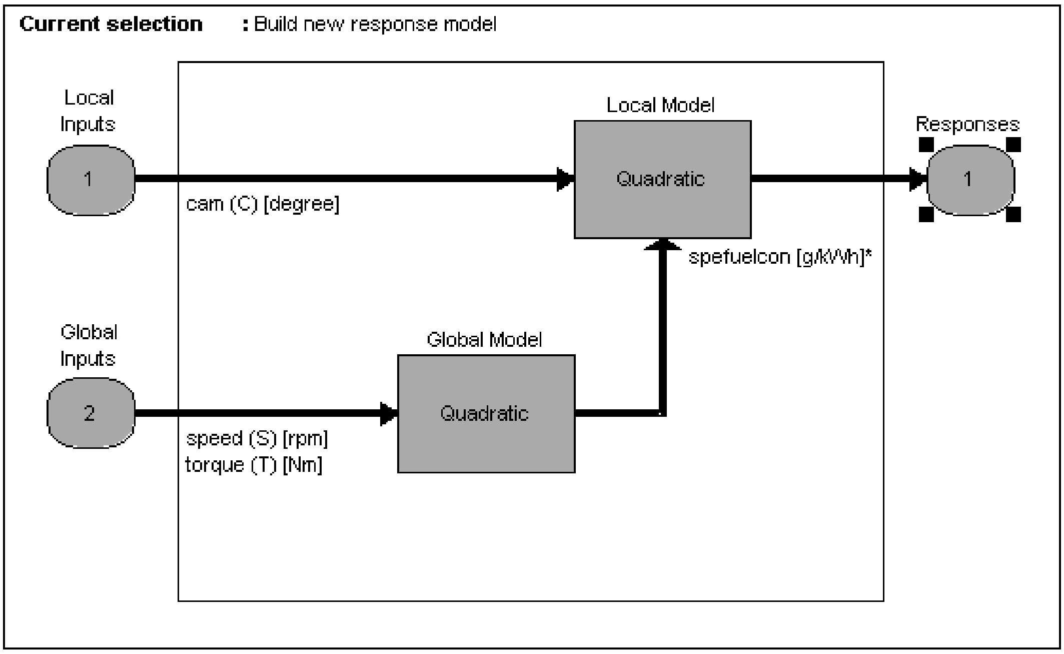

Figure 5. The algorithm for two-stage modelling

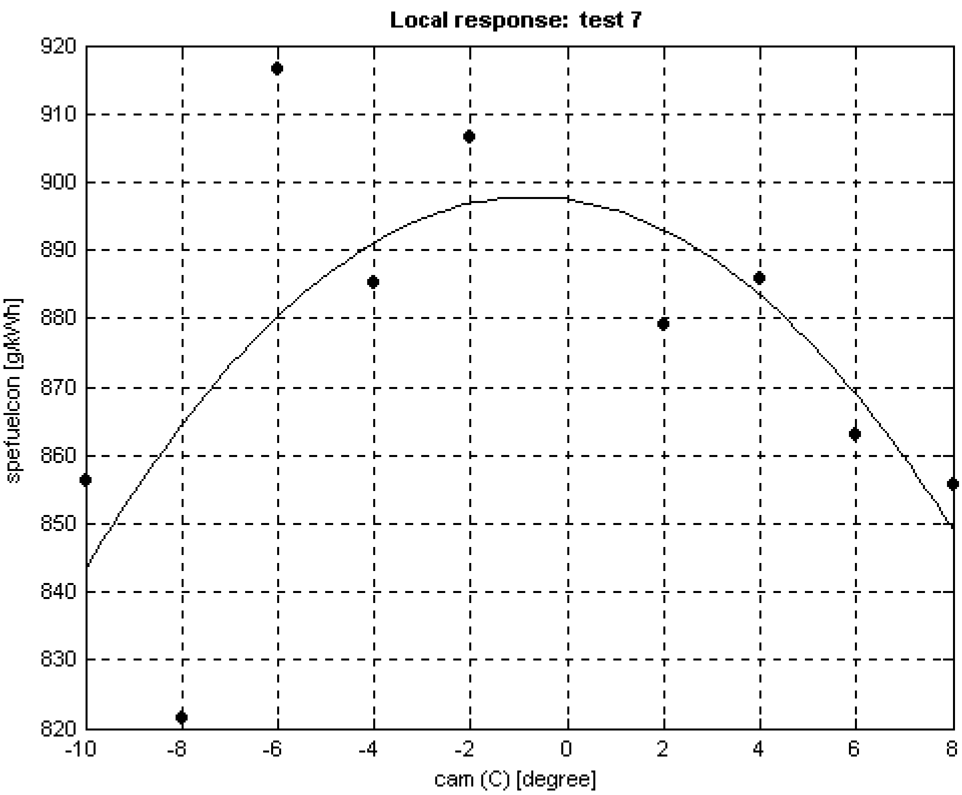

Figure 6. The fitted local quadratic function for test no:7

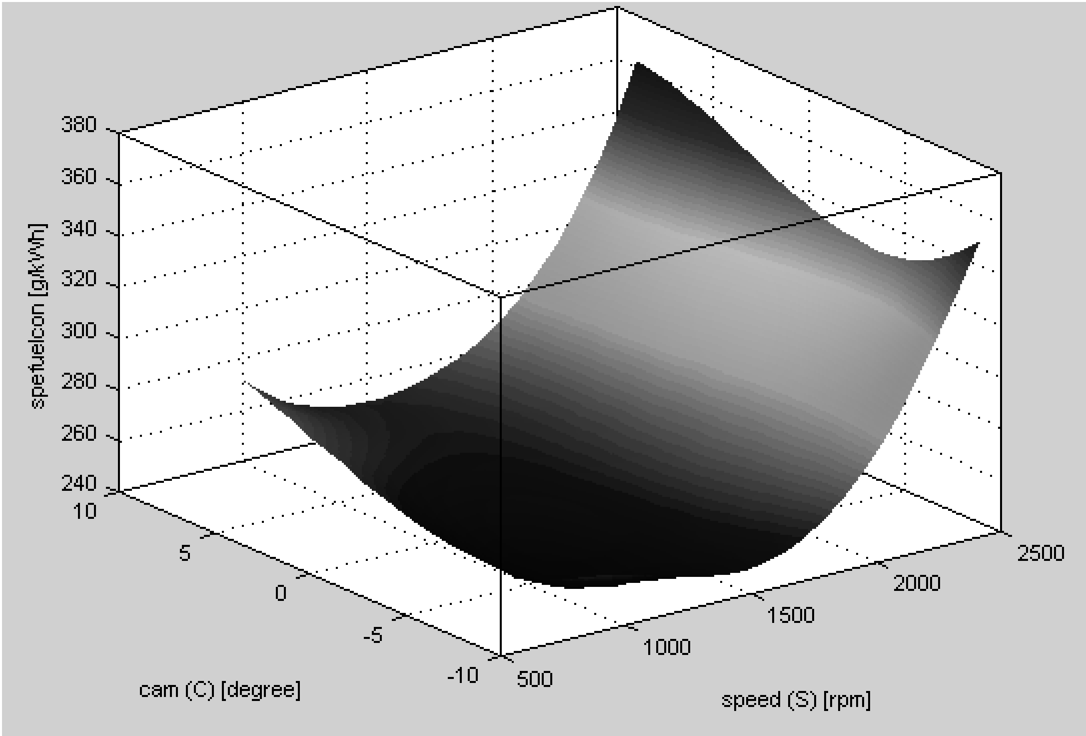

Figure 7. The response surface of the best-chosen model