Fuel 117 (2014) 833–838

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Air mass flow estimation of diesel engines using neural network

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HIGHLIGHTS

- We examine changes of air intake in diesel engine variety of engine speed.
- Experimental studies are not enough all speeds of engine.
- Neural network (NN) is able to detect the amount of air required all engine speeds.
- NN based model can be used as an alternative method for estimating the effects of diesel engine's air intake mass flow.

ARTICLE INFO

Article history:
Received 1 August 2013
Received in revised form 23 September 2013
Accepted 24 September 2013
Available online 13 October 2013

Keywords:
Neural networks
Intercooling
Air mass flow
Scaled Conjugate Gradient Algorithm
Diesel engine

ABSTRACT

Air mass management is one of major factors affecting the performance of diesel engines, where experimental studies play a significant role in the performance studies. However, the experimental studies are quite expensive and time consuming. Neural network's (NN) have been used increasingly in a variety of engineering researches. NN based model are generally developed from experimental data. The objective of the study is to investigate the adequacy of neural networks (NN) as a quicker, more secure and more robust method to determine the effects of intercooling process on performance charged diesel engine's air intake mass flow. In this study, a NN model has been developed configured tested for this purpose. The training and test data is obtained from real experimental work delivered earlier. Further details of development of NN are also demonstrated.

1. Introduction

Investigation on the effect of air mass flow to well combustion and good effective efficiency in diesel engines is a major subject. Many studies about this subject can be found in the scientific and technical literature [1–5].

Diesel engines are widely used because they are more efficient and sturdier than gasoline engines. Sen et al. [6] studied about the diesel engine combustion process is influenced by the rate of fuel injection and fuel–air mixture composition. The time interval between fuel injection and self-ignition is smaller at higher crankshaft speeds. Litak and Longwic [7] investigated about dynamics of stationary diesel engine conditions.

The compressor output temperatures are considerably higher at high loads and engine speeds. Therefore, the density of air and the amount of air induced into engine decreases in the turbocharged diesel engines. The temperature of the engine induction air must be cooled in order to avoid from this decreasing. The air mass flow, fuel properties and running parameters are directly affected the design and performance of the diesel engines. Hence, these are important for the optimization of the engine's performance [7].

This study is based data gathered by the earlier experimental study [8]. First, the engine was tested as equipped with a water-cooler intercooler, at different speeds and loads conditions. Then, the same engine was tested without intercooler at the same conditions. Measuring ranges, 1600–1800–2000–2200–2400 rpm and 18–20–22–24 CA, 400–450–500–550 N, all number of cycles for each test load, crankshaft angle values.

There are a lot of studies which have used the NN approach in the air mass flow and diesel engine performance [10–14]. Parlak et al. [12] used the neural networks to predict specific fuel consumption and exhaust temperature of a diesel engine for various injection timings. They showed that a well-trained neural network model provides fast and consistent results, making it an easy-to-use tool in preliminary studies for such thermal engineering problems. Desantes et al. [13] used in cylinder pressure increase during the intake stroke for inferring the trapped air mass. They validated the method on two different turbocharged diesel engines and compared with the standard methods. In the paper, they showed that a three layer feed-forward neural network achieved a desirable

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http://dx.doi.org/10.1016/j.fuel.2013.09.078

mapping between the inputs and outputs of the problem. Kiani Deh Kiani et al. [14] applied the NN for modeling of SI engine to predict the engine brake power, output torque and exhaust emissions (CO, CO_2, NOx and HC) of the engine. They showed that the NN provided the best accuracy in modeling the emission indices.

The main purpose of this study is to tackle with performance issues of a diesel engine with respect to air mass flow estimation for performance of turbocharged diesel engines with intercooling by using a NN. In the paper, a NN model is developed and configured based on data gathered in the earlier study [9]. NN is used to estimate air mass flow (kg/s) with intercooler and without intercooler and then, both the estimated data with NN and the data gathered from experimental study were displayed on diagrams for comparisons. A statistical analysis is conducted to explain the performance of the NN based model, where NN based model outputs are compared with experimental results. The statistical results and the comparison demonstrated that the NN based model is highly successful to determine the impact of intercooling on the performance of a turbocharged diesel engine's air intake mass flow.

2. Details of the experiment

The experimental set up is a six-cylinder, four-stroke, diesel engine with an intercooler and turbocharger which is assembled on a hydraulically dynamometer has been used. The specifications of the diesel engine are given in Table 1.

All the experiments [9] were conducted for various speeds and loads with intercooler and without intercooler. Heat exchanger is used to cool engine water. Tank volume is 300 l. Entering and leaving air temperature of intercooler is measured. Flow rate of intercooler cooling water is measured as 8.5 l/min. During the test, test parameters of engine performance, such as engine speed, load and fuel consumption data, were measured and recorded. All experimental measurements were made with a precision of 3%. The injection advance has been changed at the end of each experimental period. Measuring ranges are selected as 1600–1800–2000–2200–2400 rpm and 18–20–22–24 CA, 400–450–500–550 N for engine speed, crankshaft angle and test load values, respectively. The values of volumetric efficiency, effective engine efficiency and excess air coefficient are calculated by using of these measured values. In intercooler, cooling water was used as non-return. The temperature of cooling water used in intercooling is 17 to 19 °C. The testing scheme and test engine pictures are presented in Figs. 1 and 2.

3. Neural networks (NN)

Recently, NNs have been used successfully to solve the complex problems in various engineering fields as an alternative computational model inspired from neurological model of human brain in which all operational features of the human brain are simulate. The NN architecture is composed of one input layer, one output layer and one or more hidden layers, where the layers are composed of neurons as the fundamental processing element of NN [15–17].

Neurons in each layer are fully connected to other neurons in following layers. These NN architectures are commonly referred to as a fully interconnected feed forward multilayer perceptron. There are two biases. One of them is connected to neurons in the hidden layer and the other one is connected to neurons in output layer in the NN. The number of neurons in input and output layers may vary depending on the problem [16].

All of data used in the NN must be initialized before the training a feed work network. In the forward phase, the weighted sum of input components is calculated as:

$$net_j = \sum_{i=1}^{n} w_{ij} x_i + bias_j \quad (1)$$

where net_j is the weighted sum of the jth neuron for the input received from the preceding layer with n neurons, w_{ij} is the weight between the jth neuron and the ith neuron in the preceding layer, x_i is the output of the ith neuron in the preceding layer. The output of the jth neuron out_j is calculated with a sigmoid function as follows;

$$out_j = f(net_j) = \frac{1}{1 + e^{-(net_j)}} \quad (2)$$

During the process of training the weights are modified to capture the relationship between the input and output patterns. The training of the network is carried out by adjusting the weights. The objective of the training procedure is to find the optimal set of weights.

The most known training algorithm for the multi-layer feed-forward neural network is back-propagation algorithm. Two back-propagation training algorithms, which are gradient descent and gradient descent with momentum, are drastically slow. Therefore, several adaptive training algorithms for NN have in recent times been developed such as Conjugate Gradient Algorithm (CG) and Scaled Conjugate Gradient Algorithm (SCG). In this study, SCG is used as optimization algorithm for weights of connection links across the NN model. The detail of SCG algorithm can be found in literature [18]. Specific fuel consumption is studied in detail on diesel engines by NN [19].

The output of the NN model is compared with the experimental results to produce an error. The sum of the squares error (*SSE*) is used as the performance function for feed forward networks. The process of the training continues until the required sum of the squares error is determined. The *SSE* is defined as;

$$SSE = \sum_{i=1}^{m} (T_i - out_i)^2 \quad (3)$$

where T_i and out_i are the target outputs and output of neural network values respectively for ith output neuron, and m is the number of neurons in the output layer.

4. Numerical study

In this study, the NN based model was applied to estimate air intake mass flow with intercooling and without intercooling of turbocharged diesel engine. Firstly, the experimental studies were conducted. Then, the data of NN based model are obtained from the experimental results.

The data are divided into two parts as the training and testing sets for both models. 46 examples from the complete data set are selected as training set and used to train NN based model. 32

Table 1
Specification of the test engine [13].

Engine type	FORD 6.0 LT T/C Intercooling, DI
Stroke	4
Cylinder	6
Cylinder diameter (mm)	104.77
Piston stroke (mm)	114.9
Compression ratio	16.5/1
Max engine power (kW)	136 (2400 rpm)
Max speed (rpm)	2750–2780
Idle speed (rpm)	665–685
Engine volume (l)	5.947
Injection timing (°CA)	20
Ignition order	1–5–3–6–2–4
Engine weight (kg)	500