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Prediction of a gasoline engine performance with artificial neural network

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HIGHLIGHTS

- ▶ We model engine performance for gasoline fueled engine.
- ▶ We predict specific fuel consumption, engine power and exhaust temperature with ANN.
- ▶ The ANN approach can be used to accurately predict the engine performance parameters.

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ABSTRACT

This study deals with artificial neural network (ANN) modeling of a gasoline engine to predict the brake specific fuel consumption, effective power and exhaust temperature of the engine. To acquire data for training and testing the proposed ANN, a four-cylinder, four-stroke test engine was fuelled with gasoline having operated at different engine speeds and torques. Using some of the experimental data for training, an ANN model based on standard back-propagation algorithm for the engine was developed. Then, the performance of the ANN predictions were measured by comparing the predictions with the experimental results. Engine speed, engine torque, fuel flow rate, intake manifold mean temperature and cooling water inlet temperature have been used as the input layer, while brake specific fuel consumption, effective power and exhaust temperature have also been used separately as the output layer. It is shown that R^2 values are about 0.99 for the training and test data; RMS values are smaller than 0.02; and MEP are smaller than 2.7% for the test data. This study shows that, as an alternative to classical modeling techniques, the ANN approach can be used to accurately predict the performance, temperature and other parameters of internal combustion engines.

1. Introduction

Gasoline and diesel fuel used in internal combustion engines is produced by the refining of gasoline. Due to the facts that they can easily be derived from the energy sources already existing in the nature, and that they do not pose any problems as to storage and transportation, petroleum-based fuels have been the main fuel of engines working on both otto and diesel principles for more than one century now. Legal limitations imposed on exhaust emissions worldwide (CO, HC, carbon deposits, particles, NO_x, SO_x) worldwide encouraged researchers to study on finding ways to decrease emissions [1–7].

The fact that petroleum-based engine fuels such as gasoline and diesel fuel are at the edge of exhaustion has brought on the agenda the usage of alternative fuels in internal combustion engines. On the other hand, the environmental pollution problems caused by the exhaust gases produced by vehicles make it increasingly compulsory to use alternative fuels with superior emission features as well as different vehicle propulsion systems.

Sekmen et al. [8] modified the compression ratio (CR) of a spark-ignited, four-cylinder engine and used ethanol as alternative fuel. They examined experimentally the impact of the change in engine compression ratio on engine performance and exhaust emissions. The change in compression ratio was achieved by moving the cylinder up and down. When the compression ratio increased, engine power was raised and brake specific fuel consumption was improved. CO emissions fell in the same compression ratio range, but as the increase in compression ratio meant higher surface/volume ratio for combustion chamber, an increase was detected in HC emissions. Sayın et al. [9] modified a four-cylinder gasoline engine so that it could work with gasoline + LPG fuel in order to be able to examine the impact of using gasoline and double fuel on emission and performance parameters. According to the results obtained from this study, with double-fuel operation, 4%, 13% and 5% decrease was achieved in brake specific

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Nomenclature

FAR	fuel–air equivalence ratio
T_{ex}	exhaust temperature (°C)
N	engine speed (rpm)
P_e	effective power (kW)
T	torque (N m)
$\dot{m}$	fuel flowrate (kg/s)
T_{in}	intake manifold mean temperature (°C)
T_{cw}	cooling water inlet temperature (°C)
BSFC	brake specific fuel consumption (g/kW h)
ANN	artificial neural network
SCG	scaled conjugate gradient learning algorithm
LM	Levenberg–Marquardt learning algorithm
o	output value
p	number of pattern
R^2	absolute fraction of variance
RMS	root mean square error
MEP	mean error percentage
t	target value
f	transfer function
n	number of processing elements in the previous layer
i,j	processing elements
NET_i	the weighted sum of the input to the ith processing element
X_j	the output of the jth processing element
w_{ij}	the weights of the connections between ith and jth processing elements
w_{bi}	the weights of the biases between layers

Subscripts and superscripts

z	weighted sum

fuel consumption, CO emission, and HC emission, respectively. Batmaz [10] found that both CO and HC emissions and fuel consumption decreased, but volumetric efficiency, motor torque and output power also fell by using hydrogen as additional fuel in engines.

Çelik et al. [11] found that the methanol has greater resistance to knock and it emits lower emissions than neat gasoline. As single cylinder small engines have low compression ratio, and they run with slightly rich mixture, their power are low and emission values are high. The performance can be increased at high CR if these engines are run with fuels which have high octane number. Methanol was used at high CR to increase performance and decrease emissions of a single-cylinder engine. The results showed that some decreases were obtained in CO, CO_2 and NO_x emissions without any noticeable power loss when using methanol at the CR of 6/1. By increasing the CR from 6/1 to 10/1 with methanol, the engine power and brake thermal efficiency increased by up to 14% and 36%, respectively. Moreover, CO, CO_2 and NO_x emissions were reduced by about 37%, 30% and 22%, respectively.

The brain has features of information storage, correlation, ability to explain abstract and concrete concepts and ability to deduct new results from existing information. Artificial neural networks (ANNs), which is being able to be developed by modeling the human brain, learns with examples and is able to solve nonlinear problems. ANN can be used on problems which are very difficult or difficult to be modeled mathematically. Nonlinear property of artificial neurons enables ANN to be applied to many problems in nature.

In the literature, many engine fuel studies have shown that ANN is a very powerful modeling technique [12–22]. In this study, the input layer, engine speed, torque, fuel flow rate, the intake manifold mean temperature and cooling water inlet temperature are taken into account by developing an ANN model, is to estimate parameters such as exhaust temperature, effective power and specific fuel consumption. The equations of the parameters obtained from output layer have been optimized using the Matlab program.

2. Experimental set up and measurements

The engine used in this experiment was a four cylinder, four strokes, 1.3 l volume Ford-Escort automobile engine. In the hydraulic brakes, a DPX1A type braking system which has 100 kW power and 750 rpm rates that can rise up to 200 N m torque maximum was used. Engine test mechanism can be seen in Fig. 1.

Electronic mean rotation tachometer was used for measuring engine rotation. The sensitivity of the device for measuring number of rotation is ±0.04 rpm. During experiments, inlet and outlet temperatures of engine cooling water, the temperature of the motor oil in the pan, the insert temperature for every cylinder, temperature of exhaust gases, the temperature of fuel at the inlet of carburetor, and the temperature of the testing environment were measured by three different thermometers, namely digital, mechanical and mercurial. The measurement ranges and sensitivities of digital, mechanical and mercurial thermometers were −230 °C to −1272 °C and ±0.01 °C, 0–100 °C and ±1 °C, and 0–250 °C and ±1 °C, respectively.

Valve adjustments, point gapping, ignition advance adjustment, plug gapping, measurements of compression pressures of each cylinder and measurement of their ignition voltages were conducted according to the catalogue values of the engine and tests were initiated. In the experiments, the rotation value of the engine as kept at 1100 rpm, and the engine was loaded at 5–70 N m range by means of hydraulic dynamometer. Loading was continued at intervals until the engine reached vibration running limits. The engine rotation was increased in equal intervals of 300 rpm at 1100–4300 rpm range and loading operations were repeated at each rotation.

In the intervals within which the engine showed regular operation behavior, environment, fresh insert, exhaust, motor oil, water inlet and outlet temperatures and atmospheric pressure, oil pressure, mean relative humidity, skewed manometer deviation installed at the air tank, fuel flow rate, torque value shown by dynamometer, motor rotation value and exhaust emission values were observed as test values. The test results obtained in the experimental study have been used to train and test the ANN.

3. Artificial neural networks

The ANN is a system easily modeled on the human brain. ANNs are popular and there are many industrial situations where they can be usefully applied. They are suitable for modeling various manufacturing functions due to their ability to learn complex non-linear and multivariable relationships between process parameters. In this study, the data, 107 experimental results measured by the test unite, are divided into two parts as the training and testing sets. Eighty-one data from database are selected as training set and employed to train ANN. Twenty-six data, which are not used in the training process, are selected as the testing