Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 9 (3): 573-577, 2009
ISSN 1812-5654

An Introduction of a New Spark Advanced Control Algorithm Using Boost Simulation and Cylinder Pressure

[1]Z. Oveisi, [2]S.S. Mohtasebi, [3]V. Esfehanian and [2]A. Keyhani
[1]Technology Development Institute, ACECR, Tehran, Iran
[2]Department of Agricultural Machinery Engineering,
Faculty of Biosystem Engineering, Tehran University, Karaj, Iran
[3]Department of Mechanic Engineering, Faculty of Technical Engineering, Tehran University, Tehran, Iran

Abstract: Generally in this study, a closed-loop control algorithm is used to present suitable ignition timing at different engine operating conditions and neural network is used for estimating the peak pressure position of cylinder with only five points entries of cylinder pressure curve and then the optimum ignition timing of engine is obtained. After that, engine model in Boost software environment is used and peak pressure position of cylinder is obtained in optimum ignition timing and different speeds and loads of engine and is used for training neural network and so average value of that position is considered as the target value of controller. With comparison of several neural networks with different neuron numbers in hidden layer, optimum neural network model with structure 5-5-1 and 99.89% simulation accuracy is obtained. Net entries are five points of cylinder pressure curve and the number of hidden layer neurons is five. Also, a neuron in the output layer is used to find the peak pressure position of the cylinder. Since the control method is based on the cylinder pressure, all the equations related to the engine in this field were studied and a program for getting cylinder pressure based on crankshaft angle is written in Matlab engineering software environment. Finally, all of algorithm steps and written equations in Matlab were solved and results in engine speed of 2000 rpm with wide open throttle showed that the control algorithm can suitably keep the peak pressure position of the cylinder constant in 15.89° after top dead center while target value of the controller was 16°. Thus, the ignition timing is very close to MBT value which is equal to the peak pressure position of 16°.

Key words: MBT timing, control algorithm, peak pressure position of cylinder, neural network, controller

INTRODUCTION

Engine research is an important task for emission reduction and fuel economy improvement in vehicles. A lean burn along with direct injection gasoline engine was introduced as a new design concept for engines. In accordance with the engine design, researches in engine control are important to improve the engine performance (Yoon *et al*., 2000).

The main goal for the spark is to ignite the fuel and initiate a stable combustion, at a position that meets demands of maximizing efficiency, fulfilling emission requirements and preventing the engine from being destroyed. Focusing on engine efficiency the optimal ignition timing which gives the maximum brake torque is called MBT timing (Fig. 1) (Eriksson, 1999). Optimal ignition timing thus depends on how the flame propagates through the combustion chamber and losses such as heat

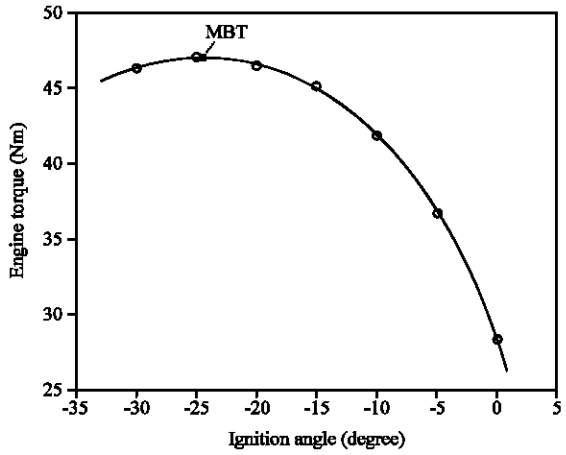

Fig. 1: Engine brake torque as a function of ignition angle. The position for Maximum Brake Torque (MBT) is marked

Corresponding Author: Z. Oveisi, Technology Development Institute, ACECR, Tehran, Iran
Tel/Fax: +98-21-66024543

transfer to walls and piston and flame propagation depends on many engine parameters. Some of them that are measured and accounted for, in recent systems are: engine speed, engine load, coolant temperature and intake air temperature.

In todays production systems the ignition timing is controlled using open-loop schemes that rely on look-up tables and they are determined through calibration experiments. The look-up tables are determined through extensive calibration experiments in either an engine or chassis dynamometer. A calibrated scheme can not guarantee good performance when non-measured parameters change, thus a feedback scheme that measures the result of ignition instead of measuring and accounting things that affect it, has the potential to guarantee good performance over the entire range of non-measured parameters, improve the efficiency and additionally reduce the calibration effort and requirements.

Flame development in SI engines is affected by many time-varying operating conditions such as engine speed, load, air-fuel ratio, coolant temperature, turbulence, intensity and so on. The cylinder pressure reflects flame development in the combustion chamber and the position of peak pressure at MBT is nearly constant for different hardware specifications and in a wide range of engine operating conditions.

Closed-loop spark timing control for optimization of fuel consumption has been used (Morris *et al*., 1982). Some algorithms were used for increasing of ignition control accuracy by dynamic simulation of engine (Tang *et al*., 1994) and some algorithms were used for increasing engine efficiency as a real-time system (Pipitone and Beccari, 2001, 2003). In recent years, various closed loop spark timing control schemes have been proposed based upon cylinder pressure measurements (Yoon *et al*., 2000; Eriksson, 1999; Zhu *et al*., 2003) or spark ionization sensing (Muller *et al*., 1999). Based on test data, it has been found that the peak cylinder pressure usually occurs around 16° ATDC at MBT timing (Yoon *et al*., 2000). It is clear that the combustion process has to be matched with the engine cylinder volume to attain the best torque. However, there is no sound theory to support the rational that peak cylinder pressure must occur around 16° ATDC (Zhu *et al*., 2003). Muller *et al*. (1999) used the scheme by neural adaptive ignition control and measure pressure in combustion chamber and Park *et al*. (2001) used neural networks and feedforward control and also Muller *et al*. (1997) used neural network in control of ignition timing but they were also based upon cylinder pressure measurements.

In this research, neural network is used for estimation of peak pressure location in the first part of the algorithm and some experimental efforts for off-line control and simulation in Boost software is carried out. Then, with the help of some equations, a virtual engine designed in Matlab software was used in a closed-loop control algorithm. The feasibility of this methodology was compared with results of others (Yoon *et al*., 2000; Eriksson, 1999; Zhu *et al*., 2003). Moreover, a commercial 2.38 L four-cylinder engine was employed in the experiment.

CORRELATION OF MBT AND LOCATION OF PEAK PRESSURE

Figure 2 shows the MBT for various engine speeds (from 2000 to 4000 rpm) and loads (from 25 to 100% throttle opening rate). The MBT shows a difference of 32° from BTDC 45° to BTDC 13° in this operating region in Fig. 2. By showing three dimensional, the relation between MBT with engine speed and load factor can be shown in Fig. 2. In the simulation of engine in Boost after each time of simulation in operating condition, the relation between location of peak pressure with various speeds and load factors can be acquired.

Figure 3 shows the location of peak pressure at MBT for the operating conditions. The LPP at MBT shows little

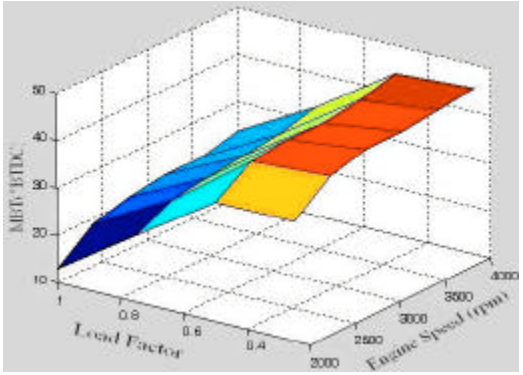

Fig. 2: MBT for various operating conditions

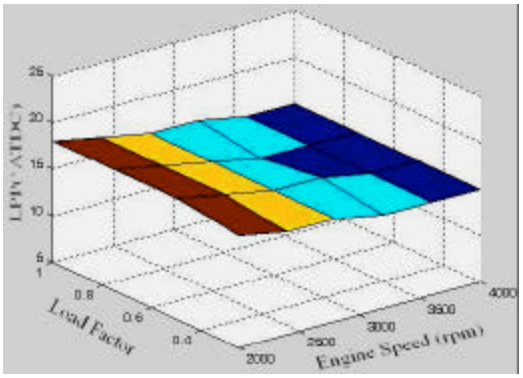

Fig. 3: Location of peak pressure at MBT for various operating conditions

difference in spite of the variation of engine speed and load factor. The mean value of the LPP at MBT was ATDC 16° and the target LPP of the spark advance controller was fixed at ATDC 16°. Locating the LPP at ATDC 16° was mentioned by Yoon *et al.* (2000), Eriksson (1999) and Zhu *et al.* (2003).

ESTIMATION OF PEAK PRESSURE LOCATION USING A FEEDFORWARD NEURAL NETWORK

The accuracy of measurement of the location of peak pressure (LPP) is determined by the A/D conversion time of combustion pressure. The sampling interval of one sample per one Crank Angle (CA) degree is adequate for acquiring reasonable values of LPP. The neural network plays an important role in mitigating the A/D conversion load of an electronic controller by increasing the sampling interval from 1 to 20° CA. The estimated location of the peak pressure can be considered as a good index for the combustion phase and can also be used as an MBT control parameter. By using neural network, the sampling interval can be decreased in such a way that only five cylinder pressure samples at -40°, -20°, 0°, 20° and 40° ATDC are needed.

The combustion pressure near the firing TDC was measured at five different locations for each engine cycle by engine simulation in the Boost software. The neural network was designed to estimate the LPP using five cylinder pressures. Figure 4 shows the structure of multi-layer feedforward neural network consisted of five sigmoid neurons in the hidden layer and two linear neurons in the output layer. Cylinder pressure from various operating conditions was acquired for the training procedure of the neural network. The operating condition is a combination of various engine speeds and load factors. The engine speed varied from 2000 to 4000 rpm by 400 rpm intervals. The load factor was varied from 25 to 100% throttle opening rate by 25% intervals. In each operating condition, spark advance variations at the stoichiometric condition were applied. There were 5 data acquisition points for each operating condition. Therefore, the cylinder pressure at 120 points (24 operating conditions × 5 acquisition points) was acquired for the training of the neural network. Each data set was attained after 50 cycles and the average value of last data was used for network training. For training and testing the neural network, 60 and 40% of data set were used, respectively.

The optimal weights of the neural network were obtained from an error back propagation algorithm using the Levenberg-Marquardt optimization technique for fast convergence (Menhaj, 2005). To determine neuron numbers in the hidden layer and to increase the comparison accuracy, 150 epochs for network was applied, but for acquiring most stability of designed network with this algorithm, number of epochs was reached to 1000. The minimum value for Mean Square Error (MSE) was set to 0.0001. When the MSE equals to 0.0001, the estimation cycle is terminated. By comparing quantitative factors of networks with various neuron numbers in hidden layer, suitable neuron numbers in the hidden layer was selected. Table 1 shows the results of designed networks with one hidden layer and various neuron numbers in the hidden layer. The transfer function in the hidden layer is sigmoid and network with five neurons in the hidden layer showed the highest accuracy. By increasing neuron numbers to higher values, no changes of MSE were observed.

Figure 5 shows the results of network simulation for five neurons in the hidden layer for data set of LPP. This figure shows a good correlation between real and predicted values.

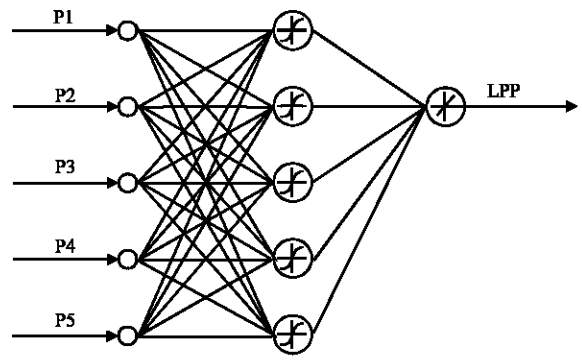

Fig. 4: Feed forward neural network for LPP estimation

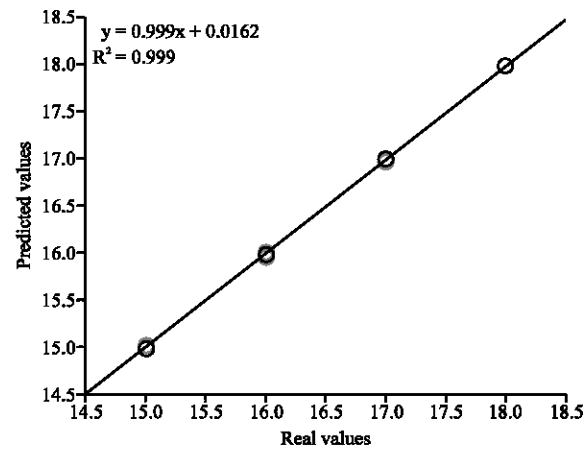

Fig. 5: The results of neural network simulation

Table 1: Quantitative factors of designed networks by using the Levenberg-Marquardt technique

	Network parameters		Network statistical parameter		
Neuron No.	Momentum	Learning rate	MSE	Prediction accuracy (%)	Coefficient of determination (R^2)
1	0.4	0.3	0.0263	99.03	0.935
3	0.4	0.3	0.0072	99.83	0.998
5	0.4	0.3	0.0001	99.89	0.999
7	0.4	0.3	0.0001	99.89	0.999

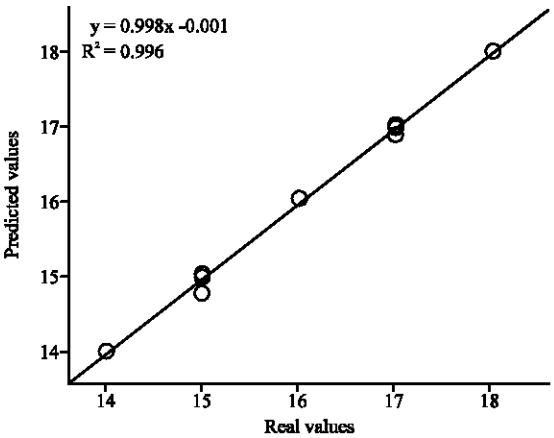

Fig. 6: The results of neural network test

Figure 6 shows the results of neural network test and by using 40% data set of LPP; with prediction accuracy of 99.91% and coefficient of determination of 0.996.

THE ALGORITHM FOR CONTROL OF SPARK ADVANCE USING PROGRAM OF DETERMINATION CYLINDER PRESSURE

In conventional engine control, the optimal spark advance is determined from the engine speed, load, air-fuel ratio and other parameters which affect the flame propagation speed. Furthermore, the MBT finding procedure in gasoline engines is complex and time consuming work. Figure 7 shows the structure of the spark advance controller using LPP. The target location of peak pressure which corresponds to the desired spark advance was calculated from the engine speed and the load factor. The difference of the LPP from the target location of peak pressure was the input of the PID controller. The base MBT value was attained from the engine operating condition and was added to the final spark advance control as the start time of heat release angle in part of the Wiebe function.

In Wiebe function program, based on Eq. 1-3, the cylinder pressure curve and the LPP is obtained (Ferguson and Kirkpatrick, 2000):

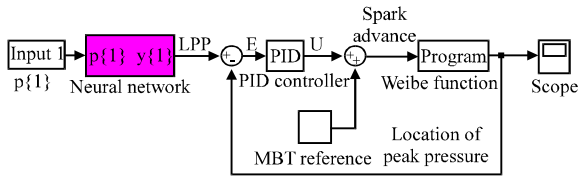

Fig. 7: Block diagram of control algorithm

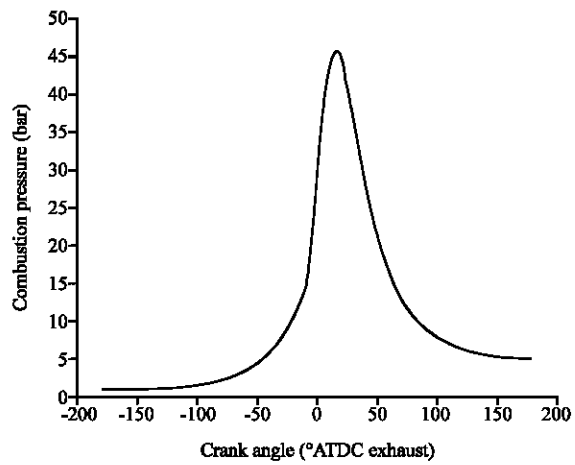

Fig. 8: Combustion pressure for determination of LPP

$$x_b(\theta) = 1 - \exp\left[-a\left(\frac{\theta - \theta_s}{\theta_d}\right)^n\right] \tag{1}$$

$$\frac{dQ}{d\theta} = Q_{in}\frac{dx_b}{d\theta}$$

$$= na\frac{Q_{in}}{\theta_d}(1 - x_b)\left(\frac{\theta - \theta_s}{\theta_d}\right)^{n-1} \tag{2}$$

$$\frac{dP}{d\theta} = -\gamma\frac{P}{V}\frac{dV}{d\theta} + \frac{\gamma - 1}{V}\left(\frac{dQ}{d\theta}\right) \tag{3}$$

Figure 8 shows the solution result of differential equation of cylinder pressure at 2000 rpm engine speed with a wide open throttle. With this program, LPP is determined for the feedforward control loop.

Figure 9 shows the result of spark advance control 2000 rpm engine speed with a wide open throttle. According to the virtual engine (Wiebe function)

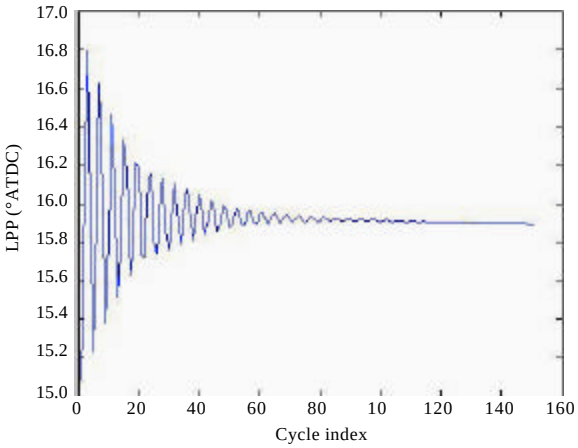

Fig. 9: Diagram of LPP in the cycle index

after the cycle index of 120, controller value of LPP was found to be to 15.89° ATDC and the target value of LPP was 16° ATDC (Fig. 9). This is a suitable result for the control algorithm. The mean value of LPP at the cycle index of 150 was found to be 15.91° ATDC. In fact, by tuning LPP as close as possible to 16° ATDC, spark advance becomes closer to MBT value.

CONCLUSION

A new spark advance control algorithm was developed using the LPP and Boost simulation software. The concept was validated over a certain engine operational range. The potential benefit of using this new spark advance control for a closed-loop control is a reduced calibration and a reduced cycle to cycle variation. The estimated location of the peak pressure can be considered as a good index for the combustion phase and can also be used as an MBT control parameter. The location of the peak pressure was regulated at 16° ATDC and by using neural network method the sampling interval increased from 1 to 20° CA.

ACKNOWLEDGMENT

Institute of vehicles, fuel and environment has made scientific facilities for this study.

REFERENCES

Eriksson, L., 1999. Spark advance modeling and control. Ph.D Thesis, Linkoping University.

Ferguson, C.R. and A.T. Kirkpatrick, 2000. Internal Combustion Engines, Applied Thermosciences. 2nd Edn., John Wiley and Sons Inc., New York, ISBN: 978-0-471-35617-2.

Menhaj, M., 2005. Fundamentals of Neural Network. 2nd Edn., Amirkabir University Publications, ISBN: 964-463-087-4.

Morris, J.E., H. Anderson and R. Smith, 1982. Retrofit Feedback Control of A/F Ratio and Ignition Timing for Fuel Economy. SAE Paper No. 820389, University of Wellington (New Zealand), Society of American Engineers, USA.

Muller, N., O. Nelles and R. Isermann, 1999. Closed loop ignition control using on-line learning of locally-tuned radial basis function networks. Proceedings of the American Control Conference, June 2-4, San Diego, CA, USA, pp: 1356-1360.

Muller, R., H.H. Hemberger and K. Baier, 1997. Engine control using neural networks: A new method in engine management system. J. Meccanica, 32: 432-430.

Park, S., P. Yoon and M. Sunwoo, 2001. Feedback error learning neural networks for spark advance control using cylinder pressure. Proc. Inst. Mech. Eng. Part D: J. Automobile Eng., 215: 625-636.

Pipitone, E. and A. Beccari, 2003. A real time platform for feedback spark advance control. Ph.D Thesis, University of Palermo.

Tang, D.L., M.F. Chang and M.C. Sultan, 1994. Predictive Engine Spark Timing Control. SAE Paper No. 940973, General Motors Corp, Society of American Engineers, USA.

Yoon, P., S. Park and M. Sunwoo, 2000. Closed-Loop Control of Spark Advance and Air-Fuel Ratio in SI Engines Using Cylinder Pressure. SAE Paper No. 2000-01-0933, Hanyang University (Korea), Society of American Engineers, USA.

Zhu, G., C.F. Daniels and J. Winkelman, 2003. MBT Timing Detection and its Closed-Loop Control Using In-Cylinder Pressure Signal. SAE Paper No. 2003-01-3266, Visteon Corporation, Society of American Engineers, USA.