American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-11, Issue-01, pp-25-31
www.ajer.org
Research Paper Open Access

Modelling of Performance Outputs of a Pneumatic Piston-Engine with Single Cylinder by means of Artificial Neural Network

M. Akif Kunt
[1] *Tavsanli Vocational Training School, Dumlupinar University, Kütahya, 43300, TURKEY*
Correspondence: mehmetakif.kunt@dpu.edu.tr

ABSTRACT : *In this study, an air-cooled gasoline engine with 13 HP power has been transformed into a pneumatic engine/compressed air engine, and engine moment experiments have been carried out according to different engine powers at constant air throttle opening and at operating pressures of 20-25-30 bar. Comparison has been made by composing the model by using artificial neural Networks (ANN) of experiments results obtained. The ANN created has two hidden layers. There are 6 neurons in the first hidden layer, and 3 neurons in the second hidden layer. The neurons included in the hidden layers and outlet layer have the function of sigmoid activation. According to the results of ANN model, Mean Absolute Error Percentage has been calculated as 0,007235, and* R^2 *value has been calculated as 0,998601. When operating pressures have been examined individually, 0.5% relative error has been obtained for operating pressure of 30 bar; 0.43% relative error for operating pressure of 25 bar; and 0.315% relative error for operating pressure of 20 bar.*
KEYWORDS *Artificial Neural Network (ANN), pneumatic engine, relative error, rotary valve, two-stroke engines*

Date of Submission: 26-12-2021 Date of acceptance: 06-01-2022

I. INTRODUCTION

Compressed air engines constitute an important alternative engine which provides expansion by using the compressed air, which does not require ignition system elements and which can enable more effective usage of local energy sources of the countries. In terms of operating principle, compressed air engines have an operating order which is reverse the compressor. Compressed air engines are pneumatic engines using the compressed air to provide expansion on the piston [1-2]. Especially due to the advantages like inexpensiveness and environment-friendly structure, pneumatic and cryogenic power systems have found usage in over populated areas such as parks, stadiums, covered garages, etc. [3-7]. Pneumatic engines are classified into two groups as two-stroke and four-stroke pneumatic engines in terms of their cycles. In Figure 1, comparison, made between compressed air engines and internal combustion engines according to their cycling manner, is shown. In operating cycle of two-stroke pneumatic engine, there are charging and exhaust strokes. During movement of the piston from TDC to BDC, charging stroke realises; and during movement from BDC to TDC, exhaust stroke realises. In operating cycle of four-stroke pneumatic engine, intake, compression, charging and exhaust transactions are included. When the engines that have been compared are evaluated in terms of the work obtained within a unit of time, it is seen that two-stroke engines are the most advantageous engines.

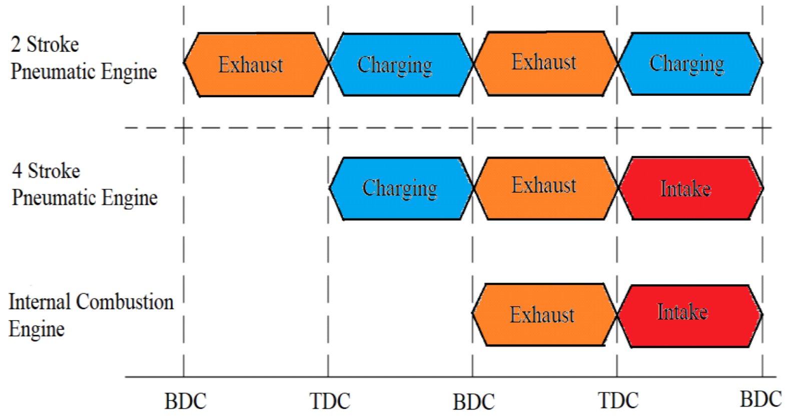

Fig. 1. Comparison of pneumatic engines and internal combustion engines according to their cyclesmatic display of experimental setup

Experimental studies related to compressed air engines are highly costly. As the operation of engine is not completely stable during the experiment, measurements cannot be taken at desired intervals. Artificial neural networks are commonly used in order to assess data obtained as a result of the measurement, made during the experiments, in a more sensitive manner. Moreover; it is considered that artificial neural networks can be beneficial for creation of the software algorithm to be composed for engine control as a result of determination of operation interval of compressed air engine, and for estimation of performance outputs of the speeds of engines that have not been tested. In solution of complex problems, techniques based merely on algorithm and mathematical methods remain insufficient [8]. Therefore; artificial neural networks, which simulate the operating principle of plain nervous system, have been developed in order for usage in solution of complex problems. Learning function in artificial neural networks is realised by calculation of the weights of synaptic connections between the cells [9]. ANNs are used to carry out the functions of estimation, classification, data association, data filtering, identification and matching, diagnosis and interpretation. ANNs enable easy modelling of systems which cannot be modelled mathematically or which are really difficult to be modelled [10]. There are a few literatures with relation to usage of artificial neural networks in assessment of the performance of compressed air engines. In this study, an air-cooled gasoline engine with 13 HP power has been transformed into a compressed air engine, and engine moment experiments have been carried out according to different engine powers at constant air throttle opening and at operating pressures of 20-25-30 and according to engine loads with different constant operating pressure. Comparison has been made by composing the model by using artificial neural networks of experiments results obtained.

II. MATERIAL AND METHODS

In order to measure the amount of air transmitted to the system in experimental setup, a Bass Instruments BF 300 brand flow-meter with metal tube float has been used. Maximum operating pressure of the flow-meter is 45 bar, and linear measurement precision is 1%. In the experiments, an engine dynamometer, whose mechanical losses were minimised, has been used. Such dynamometer has been developed as manual loading; it can make loading axially. Torque arm length of the engine dynamometer is 0.4 m. A flange has been made to engine flywheel for measuring revolution, which has also been prepared for engine dynamometer. An AVL QC34C brand pressure sensor has been used to determine internal pressures of engine cylinder.

A KISTLER 5015A brand amplifier has been used in order to increase tension signals coming from the pressure sensor and the encoder and to transmit them into data storage card. In order to transmit the data obtained from the sensors placed on the engine into computer, a National Instrument USB–6259 brand data logger produced by National Instruments company has been used. An Opkon brand encoder with optical increment and operating with 5V supply voltage has been used in order to read in-cylinder pressures on the basis of TDC. Appearance of the experimental setup is shown in Figure 2.

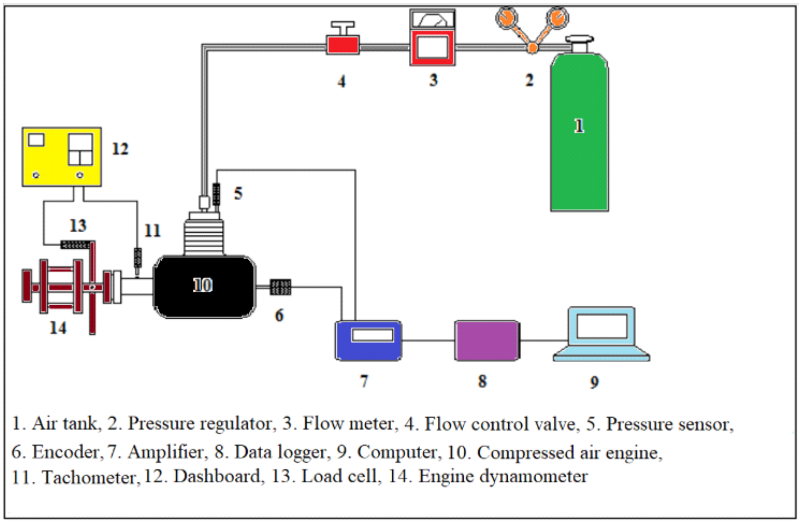

Fig. 2. Schematic display of experimental setup

A rotary valve, which is easy to manufacture, easy to install, and capable of operating at high pressures, is used to take the compressed air into the cylinder. There are many academic studies on the use of rotary valves in alternative engines [1,11]. The valve mechanism is sized, manufactured and sealed considering the maximum power point of the converted engine (Figure 3.). The exhaust camshaft is manufactured from a 20mm diameter solid shaft. This shaft is mounted on two ball bearings supported and chained to the output shaft of the engine.

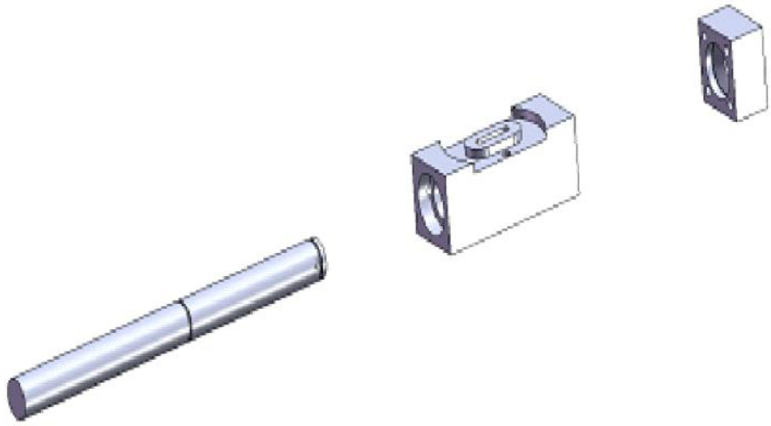

Fig. 3. Rotary valve mechanism

A. Modelling of Pneumatic Engine by ANN

Engine moment and engine power values, obtained as a result of the experimental studies carried out, have been modelled by using ANN. In the artificial neural network developed, many different neuron numbers and iteration numbers have been tested. Inlets of the developed ANN include engine speed, valve timing, operating pressure and flow rate. Outlet is the engine moment. The ANN created has two hidden layers. There are 6 neurons in the first hidden layer, and 3 neurons in the second hidden layer. The neurons included in the hidden layers and outlet layer have the function of sigmoid activation. ANN studies have been carried out by means of ANN toolbox of Matlab package programme. 90% of the data obtained from experimental studies has been used in training of the network, the remaining 10% has been used in testing. It has been tried to achieve the network structure giving the best result by changing the number of hidden layers, the number of neurons in hidden layers, the activation functions and the number of training iteration. It has been paid attention to creation of the network with least possible number of hidden layers and neurons with the thought that they would increase processing load of the computer. In consequence of the studies carried out, the best result has been obtained from the network with two hidden layers, which has 6 neurons in the first hidden layer and 3 neurons in the second hidden layer. According to test results of the ANN created, MAEP (Mean Absolute Error Percentage) value has been calculated as 0.007235, and R^2 value has been calculated as 0.998601. Outlet statement of the network created is shown below. Here, n refers to normalized engine speed, α refers to normalised valve timing, p refers to operating pressure, Q refers to air consumption flow, and in s_xy refers to the outlet of y neuron in hidden layer x. Schematic display of the ANN structure is shown in Figure 4.

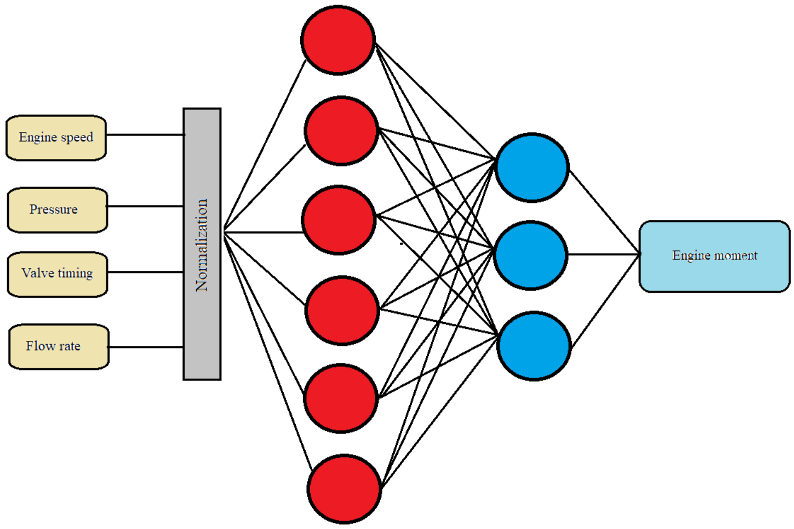

Fig. 4. ANN structure

$$s_{11} = \frac{1}{1+e^{-(33,777.\alpha+8,0827.p+9,4182.n-0,96149.Q+4,6238)}}$$

$$s_{12} = \frac{1}{1+e^{-(6,9359.\alpha-1,5724.p-0,89764.n+0,16724.Q-5,8879)}}$$

$$s_{13} = \frac{1}{1+e^{-(5,7038.\alpha+1,9706.p+5,0317.n+8,7274.Q-3,6965)}}$$

$$s_{14} = \frac{1}{1+e^{-(3,4433.\alpha+4,9463.p-2,026.n-3,5664.Q-1,0178)}}$$

$$s_{15} = \frac{1}{1+e^{-(-0,86939.\alpha-8,5743.p-1,8748.n-0,32906.Q+7,971)}}$$

$$s_{16} = \frac{1}{1+e^{-(1,9639.\alpha-2,0096.p-0,92754.n+1,0223.Q+0,99793)}}$$

$$s_{21} = \frac{1}{1+e^{-(-6,967.0,9862+9,1501.0,0029+6,9086.0,3710-10,2502.0,0908-4,2627.0,9996-5,5988.0,3736+4,5424)}}$$

$$s_{22} = \frac{1}{1+e^{-(-6,9675.0,9863+9,1501.0,00294+6,9086.0,371-10,2502.0,0908-4,2627.0,9996-5,5988.0,3736+4,5424)}}$$

$$s_{23} = \frac{1}{1+e^{-(7,3492.0,9863-8,6969.0,003+2,2163.0,371+15,3302.0,0901-16,9071.0,9996+3,9628.0,3736+5,3358)}}$$

$$M = s_{21}.1,3513 + s_{22}.1,0145 + s_{23}.1,1805 - 1,6072$$

III. FINDINGS

In Figure 5, the change in engine moment at operating pressure of 30 bar and at engine speeds with different loads is shown. The highest engine moment has been obtained as 15 Nm at engine speed of 850 rpm. At engine speeds lower than 850 rpm, engine moment has decreased. Such situation results from the decrease in charging efficiency and the increase in air leaks between piston-ring-cylinder. The biggest relative error has occurred at engine speeds of 750 rpm and 850 rpm according to ANN model. When all test points are considered, experiment results have been estimated for ANN model with a relative error of 0.5%.

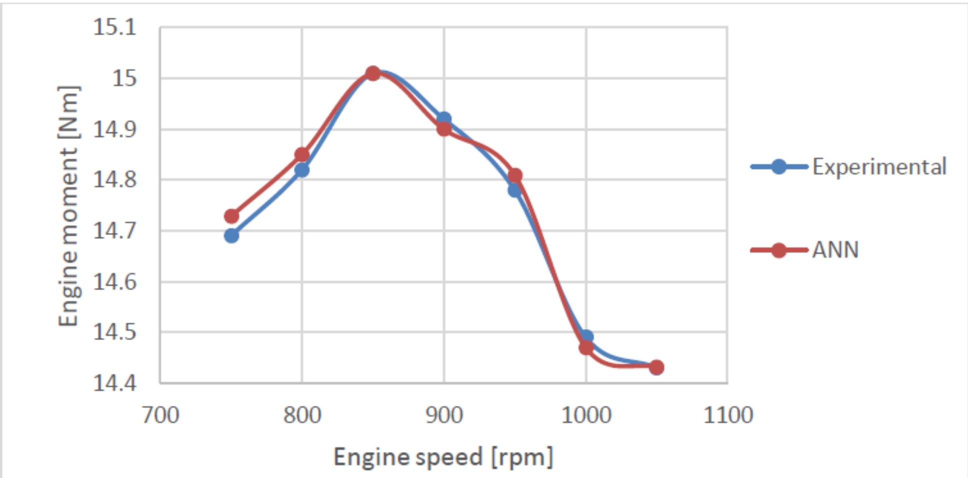

Fig. 5. Change in engine moment at operating pressure of 30 bar and at engine speeds with different loads

In Figure 6, the change in engine moment at operating pressure of 25 bar and at engine speeds with different loads is shown. The highest engine moment has been obtained as 17.56 Nm at engine speed of 700 rpm. At engine speeds lower than 700 rpm, engine moment has decreased. Such situation results from the decrease in charging efficiency and the increase in air leaks between piston-ring-cylinder. The biggest relative error has occurred as 0.43% at engine speed of 900 rpm according to ANN model.

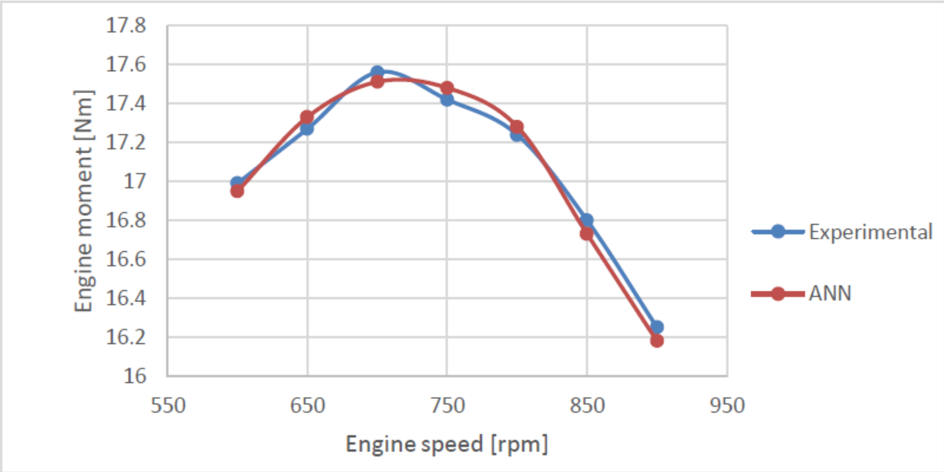

Fig. 6. Change in engine moment at operating pressure of 25 bar and at engine speeds with different loads

In Figure 7, the change in engine moment at operating pressure of 20 bar and at engine speeds with different loads is shown. The highest engine moment has been obtained as 14.9 Nm at engine speed of 450 rpm. As the engine stopped at speeds lower than 450 rpm, no experiment could be made. When all test points are considered, experiment results have been estimated for ANN model with a relative error of 0.315%. The biggest relative error has occurred at engine speeds of 550 rpm and 450 rpm according to ANN model.

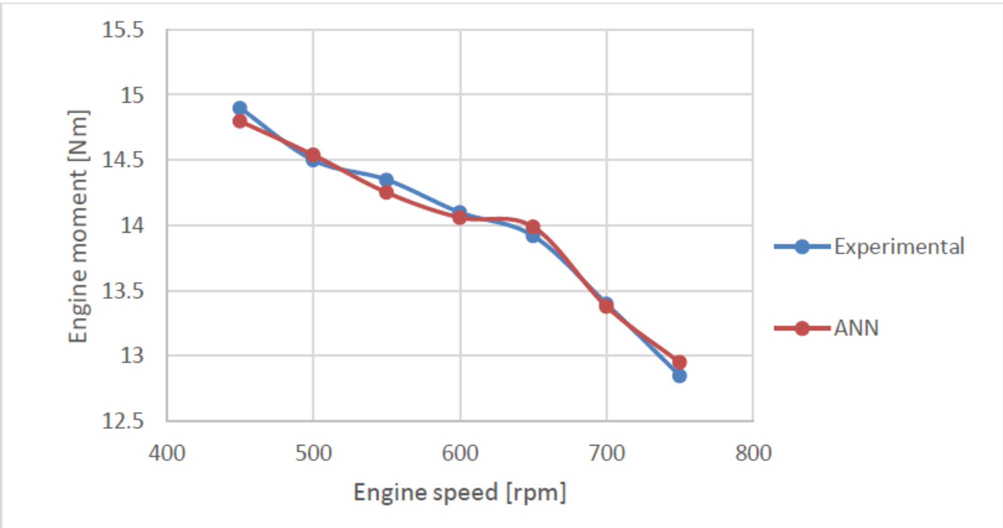

Fig. 7. Change in engine moment at operating pressure of 25 bar and at engine speeds with different loads

IV. CONCLUSION

In all operating pressures at which experiments have been made, the engine moment has increased as the amount of loading increased. Compression leaks have increased due to the highly low level of engine revolution depending on the increase of loading amount after achievement of maximum moment. The rings used do not dilate thermally due to the fact that pneumatic engines do not use fossil fuel. Such situation is the primary reason of the increase in compression leaks at low revolutions. The increase in engine speed has resulted in decrease in compression losses. In the ANN model created, MAEP (Mean Absolute Error Percentage) has been calculated as 0.007235, and R^2 value has been calculated as 0.998601. When operating pressures have been examined individually, 0.5% relative error has occurred at operating pressure of 30 bar and 0.315% relative error has occurred at operating pressure of 25 bar.

REFERENCES

[1]. M. A. Kunt, Transformation of a piston engine into a compressed air engine with rotary valve, SSRG International Journal of Mechanical Engineering. 3(11) (2016) 1-5.

[2]. H. Gunes, M. A. Kunt, Control unit design for a pneumatic engine working with an electromagnetic valve and its effect on performance of the engine, Gazi Univ, Fac. Engineering Architecture. 31(1) (2016) 1-8.

[3]. M. C. Plummer, C. A. Ordonez, R. F. Reidy, A Rewiew of liquid nitrogen propelled vehicle programs in the USA, Bulletin of the Kharkov National Automobile and Highway University. 12(13) (2000) 47-52.

[4]. A. N. Turenko, A. I. Pyatak, I. N. Kudryavtsev, I. I. Timchenko, P. V. Jadan, Ecologically clean cryogenic transport: modern state of problem, Automobile Transport. 12(13) (2000) 42-47.

[5]. A. N. Turenko, A. I. Pyatak, I. N. Kudryavtsev, I. I. Timchenko, P. V. Jadan. Pneumatic power plants for ecologically clean transport vehicles, Automobile Transport. 7(8) (2001) 193-197.

[6]. V. A. Bogomolov, I. N. Kudryavtsev, A. I. Pyatak, S. I. Bondarenko, M. C. Plummer. Development of the new croyogenic technologies for prospective kinds of automobile transport, Automobile Transport. 12 (2003) 5-7.

[7]. I. N. Kudryavtsev, A. P. Kulik, M. C. Plummer, I. Pyatak, G. I. Tochtar, Croyogenic Vehicle-Nonpolluting Vehicle for Cities, Int. Conf.,Trasport Ecology-stable Development, ECO VARNA, Varna, Bulgaria, May 15-17, 2003.

[8]. M. Khandelwal, T. N. Singh, Prediction of blast induced ground vibration sand frequency in opencast mine: A neural network approach, Journal of Sound and Vibration. 289 (2006) 711-725.

[9]. G. F. Luger, Artifical Intelligence: Structures and Strategies for Complex Problem Solving, 4th edition, Addison-Wesley. (2002).

[10]. E. Yazgan, M. Korüerek, Tıp Elektroniği, İstanbul Teknik Üniversitesi, İstanbul, 3(3) (1996).

[11]. M. Okur, F. Sahin, The effects of rotary valve and electromagnetic valve applications on turbine power on a turbo rotary engine, Journal of the Faculty of Engineering and Architecture of Gazi University. 28(1) (2013) 51-58.