APPLICATION OF THE ARTIFICIAL NEURAL NETWORKS FOR DIESEL DIAGNOSTICS

Sergey Ovcharenko, Vitaliy Minakov

This Publication has to be referred as: Ovcharenko, S[ergey] & Minakov, V[italiy] (2017). Application of the Artificial Neural Networks for Diesel Diagnostics, Proceedings of the 28th DAAAM International Symposium, pp.1208-1212, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/28th.daaam.proceedings.168

Abstract

This paper provides results of application of the artificial neural networks for diesel diagnostics based on the results of a spectral analysis of engine oil. Artificial neural network has been created and trained to identify pre-failure condition of the details of cylinder-piston group and crank-and-rod mechanism using the diesel locomotive Д49 as an example.

Keywords: diesel; technical diagnostics; spectral analysis of engine oil; artificial neural network

1. Introduction

A practice of diesel locomotive operation on Russian railways shows a diesel is the least reliable element of a locomotive which accounts for more than 40% of all unplanned repairs. Failure of the parts of crank-and-rod mechanism (CRM) and cylinder-piston group (CPG) of the diesel is more than 18% of the total number of locomotive failures. When organizing the repair of locomotives «on technical condition», it is important to have information about its technical condition while in operation. To do this, it is needed to apply different methods of diagnostics. One of the most effective methods of in-place parts diagnostics of CRM and CPG of the diesel is a method based on monitoring the current values of concentration of the wear products in a lubricant.

Engine oil is the most valuable information carrier, since during the diesel operation there is a process of wearing parts, and metal particles from the parts fall into the engine oil. New estimation technique of technical condition of CPG and CRM was developed and was proposed using the mathematical apparatus of artificial neural networks (ANN) as a result of the research. The proposed technique allows to identify the beginning of intensive wear of parts to modify the speed of increase in the concentration of wear products in engine oil by the control periods.

2. Research objectives

The research objective is to create and to train ANN, that allows to establish the fact of the beginning of intensive wear of the controlled groups of diesel parts, which characterizes its pre-failure state. Simulation results of accumulation of wear products in engine oil of diesel at various wear speed of certain groups of parts are used as initial information.

3. Creation and training of artificial neural network

Artificial neural networks are increasingly being used to solve a wide range of tasks including diagnosing technical objects. An important feature of ANN is the ability to learn and, as a result of learning, to increase its own productivity. To obtain a high-quality neural network, it is important to have sufficient amount of data for its training.

Training sample is determined by the results of modelling a process of accumulation of wear products in engine oil for groups of the chemical elements. According to the data [2], the sample was chosen for the training of ANN, consisting of the distribution of chemical elements for groups of controlled parts of diesel Д49 (CB – cylinder bushing, PP – piston pin, ARKP – articulated rod knuckle pin, PH – piston head, CR – compression rings, OSR – oil scrapper rings, CN – crankshaft neck, RD – rod journal, CBL – crankshaft bearing liner, CRL – connecting rod liner, PS – piston skirt, BBPI – bronze bearings of piston insert, BBACR – bronze bearings of articulated connecting rod). Amount of data is more than 32 thousand values. Figures 1 and 2 show the results of modeling a flow of Fe and Cu from the controlled parts at normal wear rate.

Fig. 1. Distribution of iron (Fe)

Fig. 2. Distribution of cuprum (Cu)

The most optimal network architecture for data analysis was determined as a result of the research and it is called a multilayer perceptron. The analysis of the obtained training results has showed that the highest performance indicators are provided by the ANN MJIII 9-20-14. The network has 9 neurons of input layer: the values of concentration of wear products in engine oil, a hidden layer, 14 output values corresponding to the groups of controlled parts (see Figure 3).

Fig. 3. Architecture of ANN

The goal of neural network training was minimization of difference between output y_i and desired d_k signal. The difference between output and desired signal is defined as an error signal [3,4]:

$$E(w) = \frac{1}{2} \sum_{k=1}^M \left[f \left(\sum_{i=0}^K w_{ki}^{(2)} v_i \right) - d_k \right]^2 = \frac{1}{2} \sum_{k=1}^M \left[f \left(\sum_{i=0}^K w_{ki}^{(2)} \cdot f \left(\sum_{j=0}^N w_{ij}^{(1)} x_i \right) \right) - d_k \right]^2 \quad (1)$$

Where v, x – input signals of the layer

$$f \left(\sum_{i=0}^K w_{ki}^{(2)} v_i \right) = y_k \text{ – output value of } k \text{ signal.}$$

To minimize the error signal of the network output values, we made an adjustment in the weight coefficients until the error signal doesn't adopt a steady state. Minimization of the error signal was carried out according to a delta rule, where the change in the weight coefficients of the neuron is given by:

$$\Delta w_i = \eta (d_i - y_i) \cdot x_i \quad (2)$$

where η – constant determining a speed of training

The output signals used in the paper as the wear rate of controlled parts are calculated as follows:

$$y = f \left(\left(\sum_i w_i \cdot x_i \right) - \theta \right), \quad (3)$$

where f – nonlinear activation function;

θ – quieting level of the neuron.

The training sample was divided into teaching, test and control subsets. The training subset contained 75% of the total amount of data. The test subset required to evaluate a performance of the network is 15% of the sample. The control subset was used to verify a degree of network training and contained 15% of the sample. Block diagram of the ANN training is shown in Fig. 4.

Fig. 4. Block diagram of the ANN training

MLP 9-20-14 neural network is obtained as a result of training. The network has a training efficiency of more than 94% and a training error of 5% for all parts groups (see Table 1).

Type of network	Multilayer perceptron
Architecture	9-20-14
Training efficiency	94,09
Control efficiency	92,099
Test efficiency	93,485
Error fuction	Sum of squares
Activation function of hidden neurons	Logistic
Activation function of output neurons	Logistic

Table 1. Results of ANN training

In the ANN the logistic activation function was used for hidden layer of neurons and output neurons. Logistic form of the sigmoidal nonlinearity in general form is defined as follows:

$$f_i(n) = \frac{1}{1 + e^{(-\alpha v_j(n))}},$$

$$\alpha > 0, \quad (4)$$

$$-\infty < v_j(n) < +\infty,$$

where $v_j(n)$ – local field of j neuron.

A level of trust to the results of diagnosis characterizes the fact that parameters of the trained neural network are within ist confidence interval. Confidence probability is usually denoted as $1 - \alpha$ and is selected from the values of 0,9; 0,95; 0,99. [5].

Fig. 5 provides a three-dimensional graph showing the confidence level of the ANN. The dark dots in the figure (control observations) characterize the belonging of the level of trust to the values of the objective and output functions received during the training of the ANN. Deviations of the levels do not exceed 7%, accepted for the solution of the problem.

Fig. 5. The confidence level of the ANN:
y – rest; x – objective function; z – output function

Number of properly defined predicted values serves as an estimate of the performance of developed neural-network model. Fig. 6 presents the data obtained during the test of the ANN for groups of controlled parts.

Fig. 6. Indicators of the trust level of the ANN MJIII 9-20-14

4. Conclusion

1. The ANN was developed for an analysis of dynamics of the wear products concentration in engine oil, which established the moment of intensive wear of a certain part or group of parts.
2. The diagnostics error does not exceed 10%.
3. The proposed method of evaluation of the technical state of diesel in the process of operation allows to solve the problem of transition to renovation according to technical condition.

5. References

- [1] Ovcharenko S.M. (2007). Enhancing the effectiveness of diagnostics system of diesel locomotive. Dissertation in support of candidature for a technical degree. Omsk, 2007. 368 p.
- [2] Minakov V.A. (2013). Simulation of the process of wear products accumulation in engine oil of diesel locomotive Д49 / Ovcharenko S.M., Minakov V.A. // Trans-siberian news: Scientific and Technical Journal / Omsk State Transport University. Omsk, 2013, №3 (15). 55-61 pp.
- [3] Osovski S. (2004). Neural networks for information processing / Translation from Polish by I.D. Rudinsky. – Moscow: Finance and Statistics, 2004. 344 p.
- [4] Galushkin A.I. (2010). Neural networks: basis of the theory. Galushkin. M.: 2010. 496 p.
- [5] Ovcharenko S.M., Minakov V.A. Evaluation of the technical state of diesel parts using neural-network data processing / S.M. Ovcharenko, V.A. Minakov // Control. Diagnostics.: Scientific and technical journal of the Russian Society for nondestructive testing and technical diagnostics / Publishing House "Spektr", 2 (212) February 2016. 46-50 p.