APPLICATION OF NEURAL NETWORKS FOR PREDICTING CHARACTERISTICS OF ELASTIC SUPPORTS TO PRODUCTION MACHINES

Received: 1 July 2012 / Accepted: 7 August 2012

Abstract: Vibration and noise are unavoidable in the operation of variety of technological equipment (machines, appliances, transportation and other mobile devices). Effective contribution to solving these problems provides the application of elastic supports. This paper presents the idea of applying neural networks (whose architecture is created based on table 2) in the process of defining the static characteristics of support. As a result of analysis of many different architectures applied on the results obtained by the measurement, the most favourable architecture of predictive model of neural network is presented. Deformation assessment of supports can significantly facilitate the work for people involved in the design of technology foundation.

Key words: neural networks, modeling, supports, vibroisolation

1. INTRODUCTION

Foundation of machines should damped vibrations and shocks that are transmitted from technological equipment on the environment, or from the environment to technological equipment. In such conditions, machine as technological equipment and the system of elastic supports constitute an oscillatory system, which can be viewed as a dynamic model with one (Fig. 1) or more degrees of freedom (Fig. 2.) of movements which differ in place of the malfunctions.

Vibroisolation can be active and passive. Active izloacija - a malfunction occurs in the work process of a machine that is the object of foundation. Passive izloacija - malfunction comes from the surrounding technological equipment and it is transferred to the machine over the place of reliance.

Differential equation of oscillations of the system with one degree of freedom in active isolation of vibration is given by equation (1), and in passive vibration isolation by equation (2):

\[ m\ddot{z} + b\dot{z} + cz = F_d \]  \hspace{1cm} (1)
\[ m\ddot{z} + b(z - \dot{z}_p) + c(z - \dot{z}_p) = F_d \]  \hspace{1cm} (2)

For the case of dynamic system with n - degrees of freedom of movements of differential equation of oscillations are given with system equation (3):

\[ [M][\ddot{\delta}] + [B][\dot{\delta}] + [K][\delta] = [F(t)] \]  \hspace{1cm} (3)

where: \([M]\) - matrix of mass system, \([B]\) - matrix of system damping, \([K]\) - matrix of system stiffness, \([F(t)]\) - vector of malfunctions, \([\delta], [\dot{\delta}], [\ddot{\delta}]\) - vector of acceleration, speed and movements.

An important feature of the elastic supports is
stiffness that depends both on the type and form of elasto-viscose element and in most cases is a non-linear characteristics. In such cases it is necessary to define the stiffness and muffling of the elastic support as very important quantity in identification of system dynamics by given equations (1), (2) and (3), based on loads and corresponding deformation of elasto-viscose element.

2. MEASUREMENT METHODOLOGY

To make the neural network model that provides reliable estimates of supports deformations, appropriate measurements related to the static tests of elastic supports were carried out. Supports, type A and type B (Fig. 3.), different hardness, are exposed to the effects of force in the vertical direction (Fig. 4).

Fig. 3. Supports: type A and type B

Load of supports is performed by using hydraulic pumps (1), with the cylinder (2) through a dynamometer (3) on which the value of static force $F$ is read. Static force is, through the frame (4) transferred to mat examined (6) which is mounted on a stand of the device (5), while the deformation of the mat under load and relief, is read on measurement clock (7).

Fig. 4. Device for static examination of supports in vertical direction

3. PREDICTION OF SUPPORT DEFORMATION BY USE OF NEURAL NETWORK

Neural networks are complex systems consisting of neurons, interconnected by respective links, where the knowledge of the network is stored [1]. The neural network is characterized by its architecture, the weight vectors, and transfer functions used in hidden and output layers of the network. Neurons in the input layer receive the input data. Each neuron sums inputs and one input per neuron in the input layer, but more inputs per neuron in the hidden layer. Information between neurons in different layers are transmitted using the transfer function. Due to the different weights of connections, neurons receive different signals. The output of each neuron in the output layer is compared to the desired output. In order to minimize the difference between these two outputs, weight adjustment between neurons is performed [2].

The most commonly used neural networks are multilayer perception networks trained by algorithm with back propagation [3]. Networks of this type are general-purpose models with good generalization ability and are relatively simple for practical use. For training the neural network that uses algorithm with back propagation, learning process implies that data set for training is available [4]. Each element of this set is defined by the input vector $x^{(k)} = [x_1^{(k)}, x_2^{(k)}, ..., x_n^{(k)}]$ and desired output vector $t^{(k)} = [t_1^{(k)}, t_2^{(k)}, ..., t_m^{(k)}]$. Learning objective is to determine the network parameters (connection weight and threshold of activation $b_j$) such that $t^{(k)} = [t_1^{(k)}, t_2^{(k)}, ..., t_m^{(k)}]$ is
equal to \( y^{(k)} = [y_1^{(k)}, y_2^{(k)}, \ldots, y_{l_1}^{(k)}] \). Criterion function, which describes how the actual output of the network differs from the desired is given by (4):

\[
E = \frac{1}{2} \sum_{i=1}^{N} (t_i - y_i)^2
\]  

When \( k \) sample of data set for training is led to the input, function has the following form [4]:

\[
E^{(k)} = \frac{1}{2} \sum_{i=1}^{N} (t_i^{(k)} - y_i^{(k)})^2
\]

An error in this type of network spreads backwards through the network to the input layer where according to the desired output values of neural network connection weights in the network are set. Adaptation of the connection weights \( \omega_{ij} \) and threshold of activation of neurons \( b_j \) is determined from the condition that the function (5) is minimal. Parameters of the \( n+1 \) step are determined as follows [5]:

\[
b_{jD}^{(n+1)} = b_{jD}^{(n)} - \eta \frac{\partial E^{(k)}}{\partial b_{jD}^{(k)}}
\]

\[
\omega_{ij}^{(n+1)} = \omega_{ij}^{(n)} - \eta \frac{\partial E^{(k)}}{\partial \omega_{ij}^{(k)}}
\]

where: \( l \) – mark for neuron layer, \( \eta \) – learning coefficient.

The set of input data includes: \( x_1 = \text{load} \in [N] \), \( x_2 = \text{type of support} \), \( x_3 = \text{hardness} \in [5, h_1] \), and set of output data consists of: \( y_1 = \text{deformation in case of load} \) and \( y_2 = \text{deformations in case of relief} \). Set of input and output data defined the architecture of network (Fig. 6.) in the aspect of number of neurons in input layer and output layer.

<table>
<thead>
<tr>
<th>Number</th>
<th>Input quantity</th>
<th>Bottom value</th>
<th>Top value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Load ([N])</td>
<td>250</td>
<td>30000</td>
</tr>
<tr>
<td>2.</td>
<td>Hardness ([5, h_1])</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>3.</td>
<td>Type of support</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Input quantities with values

Fig. 6. Architecture of neural network for prediction of the deformations of support

Three-layer neural network has the following architecture: the input layer - three neurons to represent the load, type of supports and hardness, one hidden layer, output layer - two neurons to calculate deformations during loading and unloading. The data are divided into three groups: data for network training, data validation and data for network testing. The training sample (60 data) was presented to the network during training, and the network was adjusted according to its error. The validation sample (20 data) was used to measure network generalisation, and to halt training when generalisation stopped improving. Finally, the testing sample (20 data) had no effect on training and so provided an independent measure of network performance during and after training. Modeling was performed in the MATLAB software system [6]. The parameters of the network architecture are given in Table 2. MATLAB code created based on the parameters given provides a satisfactory response whose evaluations confirm high accuracy of this model. Correlation coefficient is \( R = 0.99758 \), and mean absolute percentage error in case of predicting the deformations occurred by loading is 1.81%, while in case of predictions caused by unloading its value is 2.08%. Fig. 7 presents the overview of mean square error of model created.

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Input number of neurons</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td>Output number of neurons</td>
<td>2</td>
</tr>
<tr>
<td>3.</td>
<td>Nuber of neurons in hidden layer</td>
<td>12</td>
</tr>
<tr>
<td>4.</td>
<td>Transfer function in hiden layer</td>
<td>Tansig</td>
</tr>
<tr>
<td>5.</td>
<td>Transfer function in output layer</td>
<td>Purelin</td>
</tr>
<tr>
<td>6.</td>
<td>Learning function</td>
<td>Trainlm</td>
</tr>
<tr>
<td>7.</td>
<td>Number of epochs that is presented</td>
<td>300</td>
</tr>
<tr>
<td>8.</td>
<td>Number of epochs</td>
<td>10000</td>
</tr>
<tr>
<td>9.</td>
<td>Momentum</td>
<td>0.9</td>
</tr>
<tr>
<td>10.</td>
<td>Learning coefficient</td>
<td>0.05</td>
</tr>
<tr>
<td>11.</td>
<td>Training error</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 2. Parameters of architecture that has provided the best results
Performances of neural network for prediction of deformations of supports occurred by loading and unloading are given in Fig. 8. and Fig. 9.

4. CONCLUSION

Main concept of neural network with back propagation is presented in this paper and the results of its application in estimation of mat deformations made under the effect of load in vertical direction are described. Having in mind that vibrations of elastically relied technological equipment are executed around the position of stable balance and that those are small oscillations, such approach when defining static characteristics of elastic supports gives great contribution to further successful analysis of system’s dynamics.

5. ACKNOWLEDGEMENT

Authors are grateful to the company I.K.G. Guca for cooperation during realisation of experiments and writing this paper.

6. REFERENCES


Authors:
M.Sc. Nedeljko Dučić University of Kragujevac, Technical faculty Cacak, Sv. Save 65, 32000 Cacak, Serbia, Phone.: +381 32 302-733, Fax: +381 032/342-101. E-mail: nedeljkod@gmail.com

Prof. dr Žarko Ćojbašić University of Niš, Mechanical Engineering Faculty Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia. Phone.: +381 18 500666, Fax: +381 18588244. E-mail: zcojba@ni.ac.rs

Prof. dr Radomir Slavković, University of Kragujevac, Technical faculty Cacak, Sv. Save 65, 32000 Cacak, Serbia, Phone.: +381 32 302-733, Fax: +381 032/342-101. E-mail: slavkovic@tfc.kg.ac.rs

Prof. dr Snežana Radonjić University of Kragujevac, Technical faculty Cacak, Sv. Save 65, 32000 Cacak, Serbia, Phone.: +381 32 302-733, Fax: +381 032/342-101. E-mail: snezar@tfc.kg.ac.rs