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ARTIFICIAL NEURAL NETWORKS IN MODELING THE HIGH PRESSURE, SUSPENSION WATERJET CUTTING

This article presents the role of artificial neural networks in use of hydroabrasive suspensive jet cut process in laminate treatment. Three-ply layer perceptron type network with an error backpropagation learning algorithm was applied to describe this process. The article provides detailed description of neural network. This neural network simulates the treatment process and predicts its efficiency due to given parameters. The results were confronted with the laboratory results of complex studies on parameters of cutting laminate with a hydroabrasive suspension jet, whose pressure is reduced to 30 MPa.

Keywords: artificial neural networks, waterjet, modelling

1. INTRODUCTION

In the recent years, high pressure waterjet machining has been competing effectively with conventional methods of separation of materials. This is above all owing to its universal nature as a result of wide-range possibilities such as blanking complex shapes, cutting various materials or a possibility to conduct it in extreme conditions [1, 2, 8] (hazard of fire or an explosion, work under water to 6000 m, etc.).

The most serious disadvantage of the so-far existing systems for cutting with a high pressure abrasive water jet and working at pressures of 400 MPa, is the use of an injector mixer to create the jet – due to its small efficiency, especially in the case of very big differences of working media velocities. An elimination of the injector mixer and the use of the jet’s circumferential motion [3] for mixing an initially created abrasive and water mixture directly under a high pressure can result in a radical change of the situation.

The best and most widely used method to determine the effectiveness of the process of water jet cutting is to determine the maximum depth of cut. This size

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depends on the hydraulic parameters: pressure, water flow rate, nozzle sizes (diameter and length), and technologic parameters: feed rate, type and size of abrasive, abrasive flow rate, stand-off distance, etc.

2. TEST STAND AND MATERIAL

The test stand has been constructed on the basis of prototypical appliance. It is of a universal nature and enables a quick change of the configuration of hydraulic connections, which in turns makes it possible to change the mixing manner, the manner to wash out the abrasive bed as well as the change of water supply manner, and the way to carry out an initially formed abrasive water jet.

Research rig appliance has been built from two containers and four independent hydraulic branches (Figure 1), which allow adjustment of the basic flow parameters [4]. Each branch consists of the following valves: a cut-off valve, a throttle valve, a check valve and a manometer. An overflow valve performs secures Borjet01 from damage made by to high pressure. It is set at the pressure of 30 MPa.

A hydraulic monitor P26 type is the source of a high pressure. It is made on the basis of elements of a plunger pump made by WOMA company. It makes it possible to obtain the maximum pressure of 75 MPa with the rate of water flow of 75 dm³/min.

Figure 1. Schematic diagram of test device
The cutting material – laminate made by hot pressing of cotton cloths impregnated with a thermosetting phenol-formaldehyde-based binder. Due to the use of cotton cloths, the laminate has high compression strength and increased resilience, favorably lends itself to machining by drilling, cutting and forging. That is why it is widely used to make parts loaded with reversed electrical and mechanical stresses or working under friction (bushings, cams, etc.).

3. ARTIFICIAL NEURAL NETWORK

The artificial neuron is the basic unit of the artificial neuronal net similarly as in the case of neuronal biological nets, nervous cell is the basic unit. The properties of the artificial neuron answer the most important properties of the biological neuron. You should always remember that artificial equivalents functions are very simplified [9] in the relation to real nervous cells.

The artificial neuron makes up the kind of the converter about many entries and one exit. One can distinguish two blocks of the processing of the information inside him. First is block of adding up in which entrance signals are increased by suitable coefficients weights and added up then.

It was decided to choose the most typical network structure made up of three layers: input, hidden and output layers. It's called three layer perceptron with single output (in this case).

Number of input variables should be limited as much as possible, because a smaller number of input variables we obtain a simpler network:

– Smaller number of adjustable parameters during learning, and this causes learning easier and gives a better ability to generalize.
– Shorter learning time, because there is less data.

An increasing number of input data taken into account in the construction of neural model leads to an increase in the number of calls for which you need the network to determine the weights in the course of learning.

Number of input variables is limited to 5 most important. They have the biggest impact on the variable Output – cutting depth.

Few complex networks learn quickly and show repeatable behavior, although it is often mistaken behavior.

In contrast, a network with a larger number of neurons in the hidden layer, cope better with solving various tasks. Networks with more hidden neurons achieve better learning outcomes. On the basis of earlier works [3–7] it was decided to increase the number of neurons in the hidden layer to 30.

Summing up, the topology of the net consisting from 5 neurons of the input layer, 30 neurons of hidden layer and one output neuron was accepted to modeling the waterjet cutting process (Figure 2).
Input data to the entry layer [4] included- pressure, abrasive flow rate, size and diameter of nozzle and traverse speed. On the output layer cutting depth was given. In the hidden layer neuron has logistic activation function. This is an S-shaped (sigmoid) curve, with output in the range (0.1). The most commonly-used neural network is activation function. Neurons at input and output layer have linear activation function.

The quantity of entrance and output neurons was taken from the accessible results of investigations directly. To learning process ware use 96 training cases [6, 7] that include both input and target output values. From process of training excluded 10% of chances, which one used to verification of training process.

The net was learning with the algorithm of backward propagation, getting stable results after 100 000 iterations (Figure 3) with learning rate of 0.01 and momentum 0.1. To research was utilized the commercial Statistica Neural Networks for Windows application of the StatSoft Inc. company.
4. EFFECTS OF ARTIFICIAL NEURAL NETWORKS MODELING

Figure 4a presents the laboratory analysis in which the surface was adjusted using the least square method. Figure 4b shows results of the artificial neural networks modeling of abrasive suspension water jet cut in a variable pressure and traverse speed conditions. The graphs in the whole show a great convergence in the material cut depth values, a near identical character of dependence and approximate maximum value. In this case average deviation between modeled and laboratory values does not go beyond 1.07 mm and maximal deviation not go beyond 3.66 mm.

![Figure 4](image)

Figure 4. Influence of traverse speed and pressure on laminate cutting depth:
  a) results of laboratory tests, b) results of ANN prediction;
other cutting parameters: nozzle ID 2.0 mm, nozzle length 50 mm, abrasive flow rate 60 g/s

Laboratory studies results, conditioned by variable pressure and conditions of abrasive flow rate are presented in Figure 5a.

Modeling effects are shown in a Figure 5b. In this case, it can be also observed that modeling effects are compatible with lab studies. The greatest discrepancy is observed at the maximum pressure and abrasive flow rate. In this case average discrepancy between modeled and laboratory values does not go beyond 1.53 mm and maximal discrepancy not go beyond 2.97 mm.

Figure 6a depicts a laboratory study on cutting with the use of 50 mm long nozzle while Figure 6b depicts artificial neural networks modeling of that process. Here also a great modeling and lab studies compatibility is observed. Greatest discrepancy takes place in case of extreme variable values and does not exceed 14%. With the change abrasive flow rate, the depth of cut is decreasing for all
diameter of nozzle. In this case standard average discrepancy between modeled and laboratory values does not go beyond 1.33 mm and maximal discrepancy not go beyond 3.64 mm.

Figure 5. Influence of abrasive flow rate and pressure on laminate cutting depth:
- a) results of laboratory tests, b) results of ANN prediction;
  other cutting parameters: nozzle ID 2.25 mm, nozzle length 50 mm, traverse speed 4 mm/s

Figure 6. Influence of nozzle ID and abrasive flow rate on laminate cutting depth:
- a) results of laboratory tests, b) results of ANN prediction;
  other cutting parameters: nozzle length 50 mm, traverse speed 4 mm/s, pressure 28 MPa

Cutting with the use of 75 mm long nozzle is presented in Figure 7a, while its artificial neural network modeling is shown in Figure 7b.

What can be observed here, that the modeling is compatible with the laboratory studies (best compatibility at the extreme values). Diversion character is somewhat different, but the values of a maximum cut depth (diversion not exceeding 1.3 mm), at the abrasive flow rate of 90 g/s and for the biggest diameter, are approximate.
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In this case standard average discrepancy between modeled and laboratory values does not go beyond 1.65 mm, and maximal deviation not go beyond 4.9 mm.

A laboratory study on cutting with the use of 100 mm long nozzle is presented in Figure 8a, while its artificial neural network modeling is presented in Figure 8b.

In this case, modeling effects are also compatible with lab studies. Best compatibility was achieved at the low working nozzle diameters and low abrasive
discharge. The maximum depth of cut was reached at the maximum abrasive flow rate and big working nozzles diameters. In this case average deviation between modeled and laboratory values does not go beyond 1.38 mm and maximal deviation not go beyond 3.84 mm.

5. SUMMARY

The artificial neural networks use in the abrasive, suspension water jet cut depth prediction, give similar estimates in every considered case. The average deviation is 5.8 %, and maximal deviation is not more 16 %. Average discrepancy between modeled and laboratory values not go beyond 1.41 mm. Maximal discrepancy is not more 4.9 mm.

In most of the cases, the variation character due to the artificial neural network modeling was compatible with the results obtained in empirical way.

Making the neural network more complicated and choosing its parameters more adequately will result in the model being more “well-fitted” [4].

Our next step is to use already trained artificial neural network to optimize abrasive water jet cutting parameters to maximize cutting depth.

This will allow you to build a complete model of processing on the basis of partial research, without need for many time-consuming series of laboratory testing of all parameters, affecting the efficiency of the abrasive, suspension water jet cutting process.

REFERENCE

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SZTUCZNE SIECI NEURONOWE W MODELOWANIU PROCESU PRZECINANIA WYSOKOCIŚNIENIOWA STRUGĄ HYDROŚCIERNĄ

Streszczenie

W artykule przedstawiono zastosowanie sztucznych sieci neuronowych do obróbki laminatu wysokociśnieniową suspensyjną strugą hydrościerną, której ciśnienie jest zredukowane do 30 MPa. Do modelowania tego procesu użyto trójwarstwowej sieci typu perceptron z zaimplementowanym algorytmem propagacji wstecznej. Artykuł zawiera szczegółowy opis sieci neuronowej. Taka sieć symuluje proces obróbkowy i umożliwia prognozowanie (predykcję) jego efektywności w określonych warunkach. Rezultaty predykcji skonfrontowano z wynikami badań laboratoryjnych laminatu przecinanego suspensyjną strugą hydrościerną.

Dzięki użyciu sieci neuronowej będzie możliwe zbudowanie modelu predykcyjnego i dokładne określenie parametrów obróbki, adekwatnych do spodziewanych efektów, z pominięciem szczegółowych badań, a także zoptymalizowanie całego procesu przecinania.

Słowa kluczowe: sztuczne sieci neuronowe, wysokociśnieniowa struga wody, modelowanie