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Forecast Surface Quality of Abrasive Water Jet Cutting Based on Neural Network and Verified by Experiments

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Abstract: In this study, firstly, the YL12 aluminum alloy is used as experimental materials, then in the following experiments it is cut in JJ-I-type water jet machines, and 1,000 group data are gotten by measurement. In each group data, pressure, material thickness, surface roughness, abrasive flow and traversing speed are included. Next, BP artificial neural network is established. In this network, there are four inputs and one output. The inputs are pressure, material thickness, surface roughness and abrasive flow rate; the output is traverse speed. And then the BP artificial neural network is programmed by one toolbox of Matlab. Using the former 1,000 group data, the BP artificial neural network is trained, and its forecast function is obtained. Finally, the BP neural network is tested to verify through using different thickness of aluminum alloy verifies its forecast function. According to given pressure, material thickness, roughness and abrasive flow, traverse speed is predicted. The YL12 aluminum alloy is cut by the predicted traversing speed. The maximum error between the prediction values of surface roughness and the actual values of the surface roughness is 6.5 %.

Keywords: Abrasive water jet cutting, BP neural network, Surface quality, Forecast, Verification.

1. Introduction

Abrasive water jet (AWJ) is the solid liquid two phases jet beam. Through the jet beam, the material can be grinded, scraped, erode and extruded. Compared with the laser beam, plasma cutting and abrasive water jet, AWJ is new type of cutting tool and has the unique superiority—during the process, without lateral force and recoil, the workpiece will never be out of shape by mechanical force and deformation damage or mechanical vibration. Therefore, AWJ has the reputation of the most durable cutting tool [1, 2]. On the other hand, the speed of AWJ cutting is fast, the cutting gap is narrow and the quality is high. Using AWJ cutting, both of labors and material can be saved. It is easy to cooperate the NC system to process the material arbitrarily and realize the automation [3, 4].

AWJ is one of soft cutting tool, so the processing performance has its obvious disadvantage, which is called Jet Lag. As the nozzle moves as a certain speed and the workpiece has a thickness, the time of entering the workpiece and the exit of workpiece is different. The latter is comparatively slower, so this is so-called Jet Lag [5]. This lag causes arc lines on the surface, showed in Fig. 1. On the other hand, when the high energy water beam leaves the sprayer, the beam will scatter somewhat. The energy will weaken with the increase of distance, so there will be obvious taper when AWJ cutting workpiece [6]. At the same time, the lag will cause the distinct surface quality differences, that is to say, the surface on the top is smooth and the bottom is rough [7, 8]. But through the speed adjusting, in fact, energy compensation, the problem of Jet Lag will be solved.

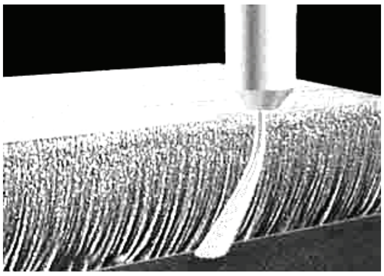

Fig. 1. Water jet section cutting diagram.

During the process of AWJ cutting, not only the factor of AWJ itself, but also the elements of the machine tool characteristic, material and technology, the relationship between AWJ parameters and the machining accuracy is highly nonlinear. As a result, it is difficult to control the processing precision and surface quality [9]. The process is often operated by experience. Based on fuzzy neural network, this study establishes the machining model of AWJ. Through the specific water jet machine tool, the sample data are obtained. Using these data, the BP neural network is trained and has prediction function. The model will realize the processing of the higher requirements of precision and intelligent control.

2. Building Model of Water Jet Cutting

2.1. Parameter Determination

The surface quality of Water Jet cutting is related to jet system, material and thickness of workpiece and the parameters of the machine tool working [10, 11]. To make it simple, selecting specific materials (YL12 duralumin) processing, so the influence of material property will not be taken into consideration.

On the side of AWJ system, considering the specific diameter of water nozzle and nozzle as well as the most commonly used abrasive particle size of abrasive research, the pressure of water jet and the flow rate of abrasive will be studied as the main parameter [12]. On the side of machine tool, due to the specific study of water jet machine tool, therefore the influence caused by machine tool's property on surface cutting quality will be neglected. In this study, only the transverse speed of nozzle will be used as machine tool parameter, the thickness of material as the processed workpiece parameter. The rate of surface roughness Ra (here, the rate of surface roughness takes the place of the surface cutting quality of workpiece.) will be as studied here, the other two elements the taper and surface morphology will be excluded [13].

2.2. Establishment of BP Neural Network

AWJ cutting technology of fuzzy artificial neural network structure is shown in Fig. 2. Fuzzy system has four inputs: E1, E2, E3 and E4. They represent the water jet pressure P, abrasive flow rate of Ma, material thickness of H, and the cutting surface roughness Ra. Fuzzy artificial neural network the system output is the speed of cutting nozzle V. If the single hidden layer neural network only be selected in the study, it is difficult to adjust the weight coefficient in neural network training, what's more, it is more complicated, and hardly to meet the requirements [14]. As a result, the double hidden layer should be chosen in FNN. But it is lack of the unity and complete theory of how to choose the hidden layer nodes [15]. The number of nodes and input / output unit are directly related to how much they have and also with the other factors [16]. This paper uses Matlab for test selection, gain better nodes.

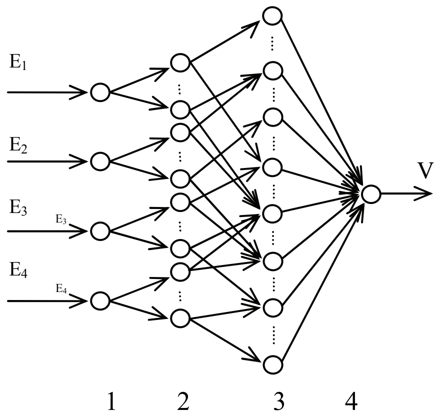

Fig. 2. FNN neural network.

Considering experimental conditions of the study, E1, E2, E3 and E4 numerical interval of each are identified as (150, 300) MPa, (0, 0.18) kg/min, (10, 30) mm, (2.5, 25) μm. On E1, E3 and E4 parameter, each defines 3 Fuzzy sets, note separately:

$B_1^1 = \{ \text{Low pressure} \}$

$B_1^2 = \{ \text{Intermediate pressure} \}$

$B_3^1 = \{ \text{The thinner} \}$

$B_3^2 = \{ \text{Moderate thickness} \}$

$B_3^3 = \{ \text{Thickness} \}$

$B_4^1 = \{ \text{Fine Processing} \}$

$B_4^2 = \{ \text{Semi fine processing} \}$

$B_4^3 = \{ \text{Rough machining} \}$

E2 is defined by 2 Fuzzy Sets, Note separately: $B_2^1 = \{ \text{Moderate} \}$, $B_2^2 = \{ \text{Overdose} \}$. Chooses Gauss function as membership function, and the cutting surface roughness of the membership function is $\mu_A(x) = e^{-\frac{x^2}{6}}$, $\mu_A(x) = e^{-\frac{(x-6.4)^2}{6}}$ and $\mu_A(x) = e^{-\frac{(x-12.5)^2}{6}}$, as shown in Fig. 2.

There are 54 fuzzy rules in fuzzy system. The general form of fuzzy rules: If $E1=B_1^l$ and $E2=B_2^l$ and $E3=B_3^l$ $E4=B_4^l$ then $y=\theta_l$ (l=1, 2, 3, …, M, M represents the number of rules) and αl is the first rule activation degree, then the fuzzy system output is:

$$V = \sum_{l=1}^{M} \theta_l \, \alpha_l \tag{1}$$

2.3. Sample Data Acquisition

Water jet machine of type JJ-I is used as the experimental device. The maximum pressure of Ultra high pressure generator is up to 380 MPa, the maximum displacement is 2.7 L/min, water spray nozzle diameter is 0.28 mm, sand nozzle diameter is 0.76 mm, cutting angle is 90 °, abrasive is 40 # garnet and target distance is 5.0 mm. In the experiment, the thickness of 20 mm, 35 mm and 50 mm YL12 duralumin will be chosen as the test piece. The TR200 roughness is used to measure the specimen surface roughness Ra.

3. Neural Network Programmed by Matlab

3.1. BP Neural Network Establishes Function

The Nnbox toolbox of Matlab software can provide specialized function newff() for establishing neural network. The method of the function's application [17]:

net =newff (A, 1, c, Trainfun)

Network properties and parameters can be stored in this net, in which the network parameters respectively stands for each input vector of the maximum or minimum value; L is a row vector and each element represents the number of neurons per layer; C is character vector and elements are each layer of neuronal transmission's function; Trainfun is a string variable, which is the network training function name.

3.2. BP Neural Network Trains Function

When the neural network is established, the network should be trained. The essence of this training is, through the repetition of comparison between input parameter and output parameter, to adjust the different layer of neurons' weights and biases, and finally to get the network which can be suited to all samples. Obviously, the prediction of network and the number of training group have direct relationship. In Matlab, network can be trained through Train function, used as following style:

net = train (net, u, y)
u: sample matrix of input
y: sample matrix of output

3.3. BP Neural Network Simulates Function

For the trained network, it can be used to deal with the practical problems. Matlab provides a function sim(), to realize the neural network's simulation function. This function is simple and convenient to be used. The using method is the actual network output matrix:

a = sim (net, p)

Type in P: processing parameter matrix.

BP neural network training scheme is shown in Fig. 3.

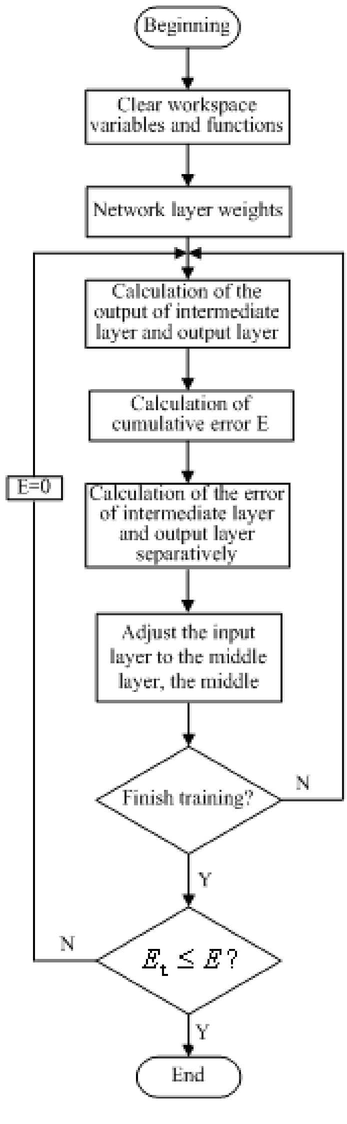

Fig. 3. Training ANN by MATLAB.

In this paper, (Fig. 2) the procedures of the BP neural network model are as follows:

```
lc
clear
load matlab;
t=output;
p=input;
[pn,minp,maxp,tn,mint,maxt] premnmx(p,t);
% Initialize neural network
net=newff(minmax(pn),[30],
{'tansig','purelin'},'trainlm');
net.trainParam.mu=0.001;
net.trainParam.show=1;
net.trainParam.mu_dec=0.2;
net.trainParam.mu_inc=10;
net.trainParam.epochs=1000;
net.trainParam.goal=0.00001
```

4. Experimental Verification

Using the trained neural network predicts the speed of different curves and then using the predicted speed programs and cuts the car model which thickness is 5mm and 8mm and material is YL12 duralumin. The recorded data are the shown in the Table 1.

$$\text{Cutting surface quality error} = \frac{\text{A given surface roughness}}{\text{A given surface roughness}} - \frac{\text{Average value of Surface roughnes}}{\text{A given surface roughness}}$$

In experimental verification, the biggest cutting quality's maximum error is 6.5 %.

5. Conclusions

According to the actual needs of sophisticated processing pieces, this study utilizes the BP neural network to establish YL12 duralumin's model cut by AWJ. Under the condition of given water beam pressure, the rate flow of abrasive quality, the thickness of AL and required processed the roughness of transverse section, the model can rapidly and reliably predict the desired nozzle's cutting speed. Using the gained experimental data to train the neural network, when the variance of transverse speed reaches to the fastest convergence, the hidden layer node number is 55, as a result, in BP neural network, 55 is chosen to be he hidden layer node number; using the trained neural network the speed of different curve's part is forecast. This speed is to be programmed and cut, at last, the biggest error of the rate of surface roughness is 6.5 %. The quality of transverse section is in the allowed range. The prediction model can be applied to practical production.

Table 1. Comparison of experimental data and prediction data.

No.	Jet Presuree (MPa)	Brasive flow (kg/min)	Thickness workpiece (mm)	Demand Roughness (μm)
1	150	0.1155	5.0	27.5
2	200	0.1480	5.5	7.8
3	150	0.1155	6.0	12.6
4	250	0.1385	6.0	60.03
5	240	0.1306	8.0	3.26
6	280	0.1540	9.0	4.15
7	260	0.1498	9.0	4.15
8	240	0.1306	8.0	4.5
9	220	0.1436	6.0	50.32
10	220	0.1480	5.5	12.5
11	180	0.1260	5.0	11.6

Table 1. (Continued).

No.	Prediction Speed (mm/min)	Target distance (mm)	Measured surface Roughness (μm)
1	29.25	5	28.11
2	57.32	5	8.31
3	82.51	6	13.02
4	175.85	7	63.03
5	28.64	8	3.34
6	37.40	6	4.32
7	32.8	5	3.98
8	38.6	6	4.32
9	158	4	48.5
10	70.36	5	11.8
11	42.6	6	11.0

Acknowledgements

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