Prediction of performance parameters in Wire EDM of HcHcr steel using Artificial Neural Network

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Abstract:- Electrical discharge machining has been extensively used for cutting intricate contours or delicate cavities that would be difficult to produce with a conventional machining methods or tools. Wire EDM is in use for a long time for cutting punches and dies, shaped pockets and other complex shaped parts. Performance of the process is mainly depends on many parameters used during process. Machining input parameters provided by the machine tool builder cannot always meet the operator's requirements. So, artificial neural network is introduced as an efficient approach to predict the values of performance parameters.

In the present research, experimental investigations have been conducted to develop predictive models for the effect of input parameters on the responses such as Material Removal Rate, surface finish and kerf width. Material tested was HcHcr steel material. Molybdenum wires of diameters 0.18 mm were used for the WEDM machine. A feed forward back propagation artificial neural network (ANN) is used to model the influence of current, pulse-ON and pulse-OFF time on material removal rate, kerf width & surface roughness. Multilayer perception model has been constructed with feed forward back propagation algorithm using peak current, pulse-ON and pulse-OFF time as input parameters and MRR and surface roughness and kerf width as the output parameters. The predicted results based on the ANN model are found to be in very close agreement with the unexposed experimental data set. The modeling results confirm the feasibility of the ANN and its good correlation with the experimental results.

Keywords- *WEDM, MRR, Kerf width, ANN, Peak current*

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I. INTRODUCTION

Wire electrical discharge machining is a thermo-electrical process in which material is eroded from the workpiece by a series of discrete sparks between the workpiece and the wire electrode (tool) separated by a thin film of dielectric fluid (de-ionized water) that is continuously fed to the machining zone to flush away the eroded particles[12]. It is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes [2]. At present, WEDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as metals, metallic alloys, graphite, of any hardness [14]. The selection of optimum machining parameters in WEDM is an important step. Improperly selected parameters may result in serious problems like lower MRR, inaccurate dimensions short-circuiting of wire, wire breakage and work surface damage which is imposing certain limits on the production schedule and also reducing productivity[6]. As MRR, Surface Roughness (Ra) and kerf width are most important responses in WEDM; various investigations have been carried out by several researchers for improving the MRR, Surface Finish and kerf width. However, the problem of selection of machining parameters is not fully depending on machine controls rather material dependent to a some extent [2].

ANNs have been widely applied in modeling many metal cutting operations, such as turning, milling and drilling. The ANN and Regression Analysis (RA) can be used for the prediction of tool–chip interface temperature which depends on cutting parameters in machining [11].

ANNs are massive parallel distributed processors made up of simple processing units or neurons. These neurons have a natural tendency for storing data and making available for use experiential information. ANNs acquire knowledge from an environment through a learning process. They create a demonstration of this knowledge in the form of inter-neuron connection strengths, generally known as synaptic weights. Neural network processing, or neuro-computing, can be seen as a non-algorithmic form of computation. It constitutes one of the main branches of the learning machines field of research [1].

II. EXPERIMENTAL SETUP

The experiments were performed on Reusable type CNC WEDM, manufactured by Jiang nan saitec NC Co. Ltd. The machine is having mechanism for recirculation of wire wounded on drum. The electrode material used was a 0.18 mm diameter molybdenum wire. A small gap of 0.011 mm is maintained between the wire and the work-piece.

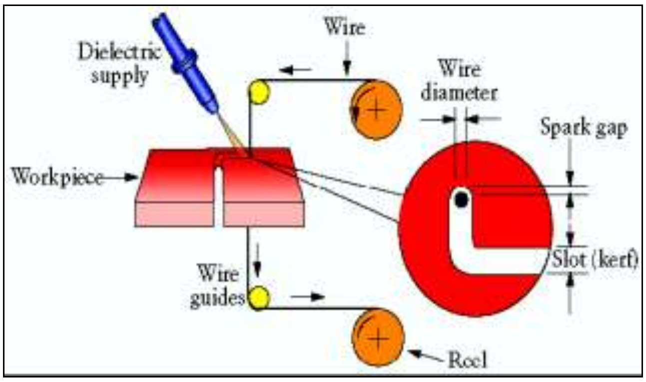

Figure 1 working mechanism of WEDM machine

The high energy density erodes material from both the wire and work piece by local melting and vaporizing. The dielectric fluid (de-ionized water) is continuously flashed through the gap along the wire, to the sparking area to remove the debris produced during the erosion. 14mm long cuts were performed for each experimental run and time was observed to calculate MRR.

A. Work Material

HcHcr steel i.e. High carbon high chromium tool steel, having 13.5 mm thickness was used for the present investigation. It is an ideal steel to use for punch and dies or injection mould tools. It is a difficult material to machine and requires a special wheel for surface grinding after heat treatment.

B. Process parameters and design

The parameters as shown in Table 1 below were fixed on the machine during machining process.

Table 1 Fixed Parameters

Parameter	Value
Dielectric	De-ionized water
Dielectric conductivity	38 mohs
Wire Tension	900 grams
Wire velocity	11.2 m/s
Wire diameter	0.18 mm
Wire material	Molybdenum
Workpiece material	HcHcr
Workpiece thickness	13.5 mm
Workpiece hardness	56 HRc

Input process parameters such as Peak Current (A), Pulse-on time (B), and Pulse-off-time (C) used in this study are shown in Table 2. These parameters and their levels were chosen based on the review of literature, experience, significance and their relevance as per the few preliminary pilot investigations. The full factorial design was chosen for this study.

Table 2 Process parameters

Symbol	Control Factors	Unit	Level 1	Level 2	Level 3
A	Current	Amp	3	5	7
B	Pulse-on Time	µs	16	32	48
C	Pulse-off Time	µs	4	8	12

In this study most important output performances in WEDM such as Material Removal Rate (MRR), Surface Roughness (Ra) and kerf width (k) were considered. The surface finish value (in µm) was obtained by measuring the mean absolute deviation, Ra (surface roughness) from the average surface level using a Computer controlled zeiss surface roughness tester. The Kerf width was measured using the profile projector. The Material Removal Rate (MRR) is calculated as,

$$MRR = k\ t\ v \quad mm^3/min$$

Where, k is the Kerf width (mm), t is the thickness of work piece (mm) and v is the Cutting speed (mm/min).The cutting speed has been evaluated under each cutting condition by dividing the cutting length (14 mm) with the required cutting time.

III. Artificial Neural Network

An artificial neural network (ANN) is architecture consists of a large numbers of neurons organized in different layers and the neurons of one layer is connected to those of another layer by means of weight. An ANN can be trained to perform a particular task by making proper adjustment of its architecture, connecting weights and other parameters. It may be considered as a non-linear statistical data modeling tool. Figure 1 show the most commonly used artificial neural network architecture known as a multi-layer perceptron (MLP) network. The ANN has three types of layers: the input, output, and the hidden layers. Each neuron on the input layer is assigned to an attribute in data and produces an output which is equal to the scaled value of the corresponding attribute [17].

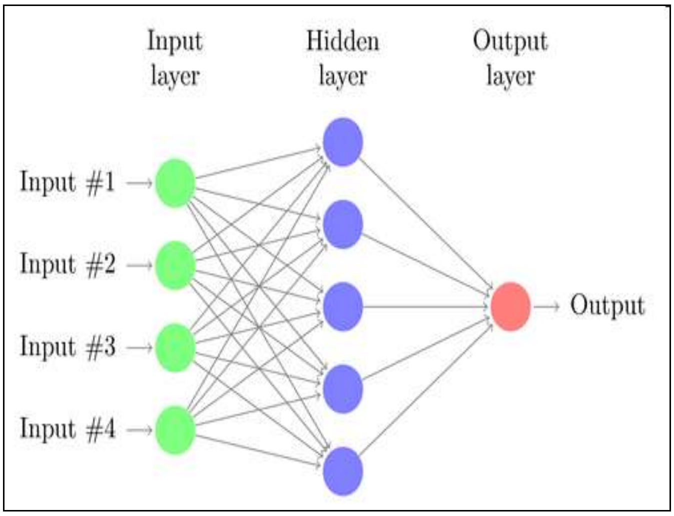

Figure 2 Multi-layer feed forward ANN structure

The hidden layers, usually numbering one or two, are intermediate between the input and output layers. Neurons on the hidden layer perform the scalar product of the neuron's input vector by the vector of weights associated to its inputs. The result of the scalar product is compared to a threshold limit. In case the limit is exceeded, the scalar product is used as an independent variable to an activation function whose output will be the neuron's output [4]. Sigmoid functions are largely employed as activation functions, although linear Gaussian and hyperbolic functions are also utilized. The output layer sums up the resulting vector from the hidden layer, thus providing the network's overall outputs. Each layer consists of neurons, those in adjacent layers being fully connected with respective weights, while those in the same layer are not. Equation 1 shows a type of activation function found commonly in the literature [7].

$$f(z) = [2/(1+e^{-z})] - 1$$

Table 3 Experiment results

Exp no.	Current	Ton	T off	MRR	SR	KW
1	3	16	4	2.83	2.45	0.212
2	3	16	8	2.77	2.40	0.223
3	3	16	12	2.60	2.25	0.234
4	3	32	4	2.97	2.57	0.245
5	3	32	8	2.67	2.50	0.212
6	3	32	12	2.40	2.25	0.223
7	3	48	4	3.31	2.95	0.205
8	3	48	8	3.07	2.73	0.211
9	3	48	12	2.84	2.53	0.218
10	5	16	4	2.76	2.45	0.225
11	5	16	8	2.84	2.53	0.218
12	5	16	12	2.42	2.15	0.185
13	5	32	4	5.05	3.06	0.247
14	5	32	8	4.67	2.83	0.229
15	5	32	12	4.62	2.80	0.226
16	5	48	4	8.10	2.93	0.228
17	5	48	8	7.45	3.05	0.217
18	5	48	12	6.86	3.17	0.206
19	7	16	4	4.20	2.47	0.237
20	7	16	8	3.96	2.33	0.224
21	7	16	12	3.74	2.20	0.211
22	7	32	4	10.88	2.90	0.234
23	7	32	8	10.44	2.78	0.225
24	7	32	12	10.03	2.67	0.216
25	7	48	4	12.12	3.12	0.248
26	7	48	8	11.55	2.97	0.236
27	7	48	12	11.20	2.88	0.229

For each neuron in the hidden or output layer, the input-output transformation employed is defined as in equation

$$v = F\left(\sum_{h=1}^{H} w_h u_h + w_0\right)$$

where v is the output of the neuron, H is the total number of neurons in the previous layer, uh is the output of the hth neuron in the previous layer, wh is the corresponding connection weight, w_0 is the bias (or intercept), and F is the nonlinear activation function [7]. Neurons on the output layer perform a weighted sum over the outcomes of the hidden layer to generate network outputs.

Easy NN computer software was used for ANN modeling because of its simplicity in developing and training models. ANN Model with architecture 3_3_3 was created for the prediction model. The neural network training data obtained from the experimental result data listed in Table 3 is used for developing neural network model. Observation number 5, 10, 15, 21 & 25 were not included in the network training. These data sets were used for the verification of the ANN model.
The criteria for the termination of training selected are permissible error and maximum number of cycles in training and validation. The limiting value for all the errors over the entire data is selected as 0.02 (2%) while the permissible error for validation sets is specified as of the target value. The maximum number of training cycles is limited to 500000 for each learning set.

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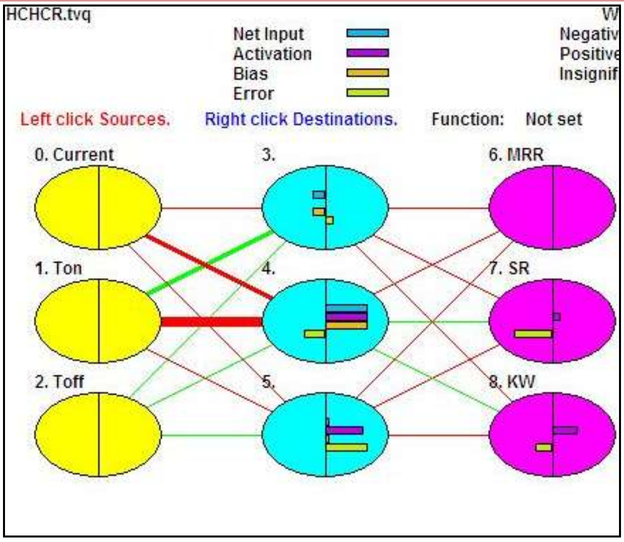

Figure 1 ANN Model with architecture 3_3_3

however, depends on the objective assessment of their potential and on the identification of systematic and efficient ways to deliver neural models of high performance.

The model served as a tool to calculate the resulting MRR, surface roughness and kerf-width based on variation of different input parameters without need to conduct any experimental work.

The developed ANN model shows a good correlation both for training and testing data sets, thus validating the model. The overall error between the experimental and ANN predicted response parameter is found to be less than 7.76 %. So, this ANN model can be used to predict performance parameters of wire EDM based on given input. It can also be used to give artificial intelligence to the machine controller for the adaptive control for determining desirable output for a given input.

Table 4 comparison of ANN predicted and Actual output parameters

Exp no.	Experimental MRR	ANN Predicted MRR	Error %	Exp. SR	ANN Predicted SR	Error %	Exp. KW	ANN Predicted KW	Error %
5	2.67	2.73	2.25	2.50	2.39	-4.40	0.212	0.220	3.77
10	2.76	2.60	-5.80	2.45	2.54	3.67	0.225	0.213	-5.33
15	4.62	4.27	-7.58	2.80	2.64	-5.71	0.226	0.237	4.87
21	3.74	3.87	3.48	2.20	2.09	-5.00	0.211	0.219	3.79
25	12.12	13.06	7.76	3.12	3.24	3.85	0.248	0.261	5.24

Thus, training stops when any one of the above criteria namely, all errors being less than 0.05, all validation point within 5% of target values completed. The learning rate is kept to momentum as 0.8 for the stable learning and convergence of weights. For training and validation 80-20 rule is used.

After training of network, prediction queries were generated with input from experiment set number 5, 10, 15, 21 & 25. The ANN predicted output was compared to actual experimental output as shown in table 4.

IV. CONCLUSION

A good correlation is observed between the predicted and the experimental measurements. Accurate and reliable models are becoming more and more necessary to quickly acquire knowledge of operations involving new tools and materials. Neural networks are a suitable tool for the task. Their use,

In the experimentation it is also observed that there exists a highly non-linear relationship between the response parameters and the selected electro discharge machining process parameters.

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