Journal of Achievements in Materials and Manufacturing Engineering

VOLUME 27
ISSUE 2
April
2008

Optimisation of electro discharge machining parameters

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Received 31.01.2008; published in revised form 01.04.2008

Analysis and modelling

ABSTRACT

Purpose: Electro discharge machining (EDM) is one of the most effective non-conventional machining methods. This method is the best condidate in machining of ceramics and carbide materials.

Design/methodology/approach: The complexity and non-linear nature of EDM from one side, and occurrence of instability phenomenon due to the different input setting up parameters especially in machining of carbon-based materials such as non-oxide ceramics, on the other side, make the modeling of EDM process impossible with conventional methods. What is presented in this paper is the optimization and control of EDM process using the neural model predictive control method.

Findings: The results of implementation of control system on a sinking ED machine and an EDM system that has been set with an expert user, has been compared.

Research limitations/implications: To achieve instantaneous data from machining condition, the new method of fuzzy analysis of single machining pulses and computing the magnitude of system condition in the form of a real number between 0 and 1, has been used.

Originality/value: The testing results from ED machining of WC-Co confirms the capability of the system of predictive controller model based on neural network with 32.8% efficiency increasing in stock removal rate.

Keywords: Numerical techniques; Optimization; Fuzzy logic; EDM; Model predictive control

1. Introduction

The object of special interest of researchers is lifting the machine,s efficiency and reliability, during the process of designing the machines [1]. The necessity for frequent product line changes causes the development in flexible production systems [2]. Some specifics of modern machine tool are included over modules, as rotation table, precise high RPM spindle, bar magazine, tools magazine, workpiece magazine, laser zero point measurment system, cutting forces dynamometers for diagnostic of process, frequencies sensor, acoustic sensors [3]. The instability phenomenon in electro discharge machining (EDM) is the most important factor in rapid tool wear and great decrement in stock removal rate. Occurrence of this phenomenon especially in machining of carbon-based materials such as carbides and non-oxide ceramics due to carbon immanency of workpiece and convenient dielectric is inescapable. The researches show that the arcing phenomenon as the symbol of instability in EDM, has unknown stochastic distributions caused by different input parameters. Input setting parameters to obtain the desired outputs such as high stock removal rate and low tool wear ratio has been accomplished manually based on user's experience and without any optimization. Generally, methods used to model the processes in form of "black box" has been suggested for modeling of such processes. Therefore, a method for physically modeling will be effective and reliable that updates its knowledge about the process regularly. One of the most fundamental criteria in the design of modern mechanical structures are their dynamical propreties, as they have a direct impact on the vibrations of the system, noise emission, fatigue resistance, controllability and stability [4]. Challenging problems for scientific research are the requirements concerning mechatronic system, for example their exact positioning working velocity, control and dimensions [5]. Optimization of non-linear models with unknown transfer functions usually is possible using methods based on artificial intelligence. The first research to distinguish the pulse type with artificial intelligence is carried out in 1997 by Kao and Tarng [6]. They tried to make distinctions among pulse types instantaneously via artificial neural networks. Also, Liu and Tarng in the same time modeled the EDM using neural networks. In1997 Spedding and Wang tried to optimize the surface characterization and input parameters via modeling of wire-EDM process [7]. According to the determination of transformation function via the mathematical relations between input and output vectors, the capability computation of the fitness function value in optimization process will be determined [8]. On the other hand, in the process not being mathematically formulated, the relationship between input and output vectors must be presented, so that the output vectors with any input and desired accuracy respect to the physical process, should be available [9]. The artificial neural networks are the best choice to model the physical processes in the black box format [10,11]. It is possible to achieve high stock removal rate and low tool wear ratio with good surface finishing if the stability of machining process as an effective mode in output parameters is guaranteed [12].

In this paper, the method of model predictive control based on artificial neural networks with output parameters of the system to minimize the number of non-successive pulses is used. To determine the value of stability process parameter, a fuzzy analysis method is developed to distinguish the single pulse discharge type.

2. Pulse type distinction using fuzzy logic

Up to now, the distinction of pulse type based on detection of normal discharge from arc and other abnormal pulses has been accomplished with different methods. Determination of a threshold on discharge voltage so that its lowest level is higher than arcing voltage level, measuring the discharge delay time which is zero or very small in quasi arcing and arcing discharge and analysis of high frequency elements on gap voltage-time diagram pulse by pulse, are the fundamentals of classical pulse distinction methods in EDM [13]. Although the pulse type distinction with artificial intelligence-based methods are usually successful, but, the stability analysis of the system via studying of single pulse and assigning a relative instability factor is possible only by using fuzzy logic. The fuzzy approach to microscopic pulse distinction obtained from pulse train in gap, is based on two main reasons:

- The stable and unstable machining boundary zone especially in carbide materials is quite ambiguous.
- Too many linguistic rules are used by EDM specialists in pulse interpretation.

The second expression not only shows the fuzzy analytical ability of pulse train, but, the decision based on fuzzy interpretation in EDM process [14]. An example of such linguistic rules about single-pulse interpretation is; if<discharge delay time is small> and <average gap voltage is low> then <the discharge is arc>.The factors used in fuzzy analysis are as follows:

- Average discharge voltage from breakdown to the end of pulse on-time.
- Discharge delay time.
- High-frequency elements on pulse voltage-time diagram.

The third factor is neglected due to the unnecessary of process analysis in frequency field and avoiding of massive calculations. The first two mentioned factors determine the pulse type by using linguistic rules bellow:

1. If <the delay time is too short> and <the average discharge voltage is low> then <the pulse is arc>.
2. If <the delay time is medium> and <average discharge voltage is medium> then <the pulse is normal>.
3. If <the discharge average voltage is too low> then <the pulse is short circuit>.
4. If <the delay time is long> and <average discharge voltage is high> then<the pulse is open circuit>.

The above linguistic rules with fuzzy of two parameters (discharge delay time and average discharge voltage) and suitable fuzzy operators' creation and also using appropriate fuzzy related to the input parameters will be able to allocate a number between 0 and 1 to the discharge condition of any pulses. Therefore, after nom-fuzzy operations, this fuzzy analysis is able to determine numerically the condition of any machining pulses. For n pulses recorded, the condition factor of system is as follows:

$$\lambda_k = \frac{1}{n}\sum_{i=1}^{n}\gamma_i \text{ , } k = 1,2,\cdots,n \qquad (1)$$

where γ_k is numerical average condition factor of each pulse. It is obvious that, the more number of pulses recorded, the higher accuracy in condition factor of system results, indeed. This subject refers to the situation of dielectric in machining zone, so that, any debris in this position may cause abnormal discharges. Therefore, increasing in number of pulses recorded decreases the total errors. In this manner, condition factor of the system especially after any set up variation in current domain, pulse on and off time, gap size and the speed of head displacement due to voltage variation, will be determined via the fuzzy system created. Therefore, this system acts as a fuzzy sensor for machining process. This subject is very important in closed loop control systems. Figure1 shows the number of pulses recorded from machining zone with open-circuit voltages equal to 250V.

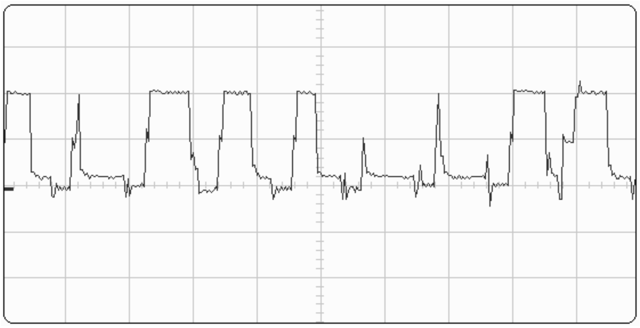

Fig. 1. Typical pulse train sample in EDM process

The condition factor of the system is calculated from 15 sample of the pulse train.

3. Artificial neural networks and modeling of EDM process

In this research the three layered perceptions neural network and sigmoid transfer function at the first and second layer and linear function at external layer, is used to model EDM sinking process. In 1987 Cybenco and Nielsen proved that this network is able to estimate any non-linear function with desired accuracy. The neuron numbers of external layer is determined with the number of output parameters. The error back propagation is used as a training algorithm. This kind of neural network is very usual and skilled in simultaneously monitoring and at the same rank, very simple in communications and network structure.

3.1. Multi-layer perceptions neural network

The multi-layer perceptions neural network is formed from numerous neurons with parallel connection, which are jointed in several layers [15]. The structure of this network contains of network's input data, numbers of hidden middle layers with numerous neurons in each layer and an external layer with neurons connected to output. This kind of network due to its sigmoid transferred function in the middle layers and linear transferred function at the external layer has universal approximation capability. According to the complexity and reciprocal affections of various machining parameters, the nature of EDM process is not completely cleared to the user; therefore, the kind of the selected network should have universal approximation capability. Input and output parameters classification defines the cell's kind of network somehow. In particular, the single output parameter of the desired network is considered as EDM condition system. This parameter is the output of fuzzy sensor and a real number between zero and one. Therefore, naturally to create a meaningful similarity between input and output vectors terms in data training network, the components value of gravimetric matrix and bias vector in each neuron connection, is varied. The network training with real data means the creation of optimized values of components in gravimetric matrixes and biases with the aim of one by one similarity creation between input and output parameters terms. The error back propagation and Levenbergg-Marquardt algorithms are used for training of multi-layered perception neural networks. On and off pulse times, discharge current, gap size and its variation rate are the input parameters of network.

4. Operational method

The control of predicting EDM model via neural network to optimize WC-Co machining process on a die sinking machine with gap control system is carried out. The capability of the system with and without gap control system is compared. Table 1 shows the testing conditions.

According to the criteria system condition the train of pulses recorded, the system stability factor is defined as follows:

Table 1
ED Machining parameters of sampled pulse train

Tool	Copper with 10 mm dia
Workpiece	WC-Co
Machine	CHARMILLES-20 ZNC
Dielectric	Kerosene
Open Circuit Voltage (V)	225
Max. Allowed Current (A)	1.5,3.5,7.5,11
Pulse On - Time (µS)	35~1000
Pulse Off - Time (µS)	35~1000
Gain of Gap Magnitude(KΩ)	120~980
Gain of Head Reaction Speed(KΩ)	1.32~91.2
Oscilloscope Setting	100 V/div & 100 µS/div
Oscilloscope Sampling Rate	312 Samples/sec
Pulse Train Condition Factor	0.6247

$$s.s.f = \frac{1}{T}(\lambda_{k+1} - \lambda_k) \tag{2}$$

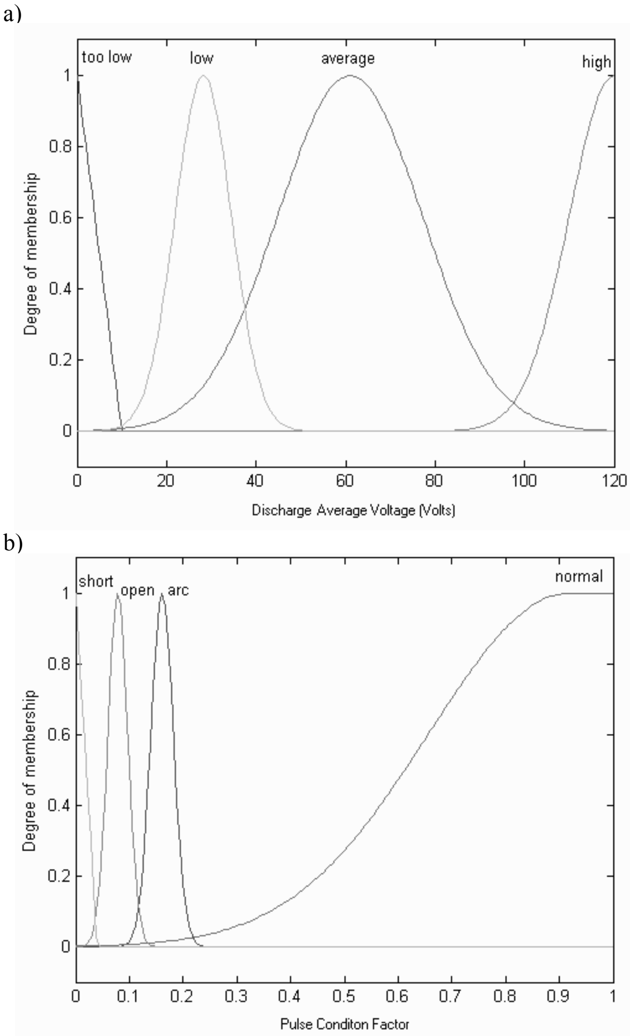

Fig. 2. Membership function of: (a) discharge average voltage, (b) pulse condition factor as an input of fuzzy system

Where T, λ_k and λ_{k+1} are the time between two samples recorded, condition factors in recorded pulses k and $k+1$ respectively. Sampling is done via a digital oscilloscope with sampling capability to 20 MHz as voltage respect to time diagram and the results are analyzed as a matrix form in phase systems, box tool of MATLAB software. The results of machining phase analysis contains instantaneous system condition which is a real number between zero and one, is used to create couple training data of neural network. Input data are: discharge voltage, discharge current (numbers of activated transistors), gap size, head reaction speed and pulse on-off times. The phase sensor elements such as preliminaries and their membership functions like mean discharge voltage, including output parameters such as arcing, normal and open circuit pulses and their related functions are shown in Figure 2.

These factors are used to determine the system condition via time-related functions mentioned in section 2 with the same effecting gravity. The surface transmitted from two inputs and single output parameters is shown in Figure 3.

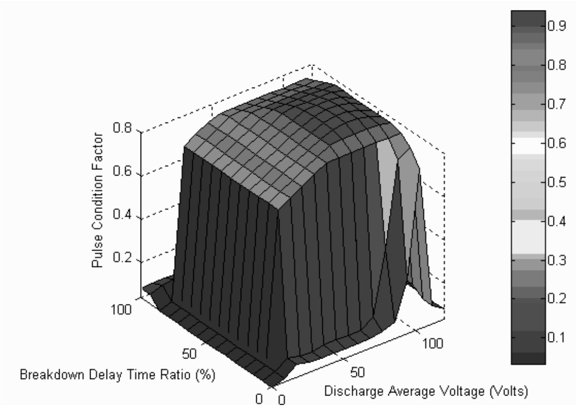

Fig. 3. Fuzzy assigning surface of two input and one output

5. Optimization

After neural network training with primary input data which is storaged in computer's lateral memory and its corresponding output data which is output data is done via optimization algorithm. In complex and non-linear physical processes optimization, since the trapping of optimization algorithm in relativistic extrimums is sometimes possible, necessity preparations to increase the mutation and instantaneous variation of generation conditions via generic algorithm should be under consideration. Primary data test which are later training data of neural network, also should cover space of the input variations condition. The last obtained data as input data which leads the system to the maximum number of condition and real condition number after system parameters variation are used for training of neural network and increase its knowledge. The continuous training process of network can be stopped after certainty of any following conditions has been established:

- The number that indicates the final condition of system is reached to the necessity state and approved distance of desired number.
- The network's training number and its re-optimization does not exceed to the operator's desired number.
- For several serial optimizations, system parameters should cause a decrease in condition number. This subject can be as a warning for over-training of network.

6. Discussion and results

Two grades of WC-Co are tested in this research. Testing conditions are shown in Table 1. The results obtained from predictive controller model based on neural network and also by expert user. This figure shows that how the carbon bridge between two electrodes is distinguishable via the extremely dropped of instantaneous condition/time curve. The stock removal rate for both samples is shown in Figure 3. The structure of predictive controller model is done via PC in MATLAB software area with hard wary parallel contour and the desired sets up are carried out by suitable connector circuits on EDM system.

The comparison between the set up obtained via machine and expert user on EDM is done with 8 hours machining that has proved the capability of the system. To improve ED machining parameters on carbon-based materials the predictive controller system based on neural network is designed and dismantled and the results from testing carried out on WC-Co via electro discharge sinking machine is analyzed. The testing results from ED machining of WC-Co confirms the capability of the system of predictive controller model based on neural network with 32.8% efficiency increasing in stock removal rate.

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