Parametric study and optimization of regression model in WEDM using genetic algorithm

G Daniel1, Girishkumar2, Ali-Ul-Hasan-Rizvi3 and P Mathan Kumar1,*  
1Al-Falah University, Dhauj, Faridabad, India.  
2Delhi Technological University, Delhi, India.  
3Department of Mechanical Engineering, Bannari Amman Institute of Technology, Sathyamangalam.  
*Author for correspondence E-mail: mathankumarp@bitsathy.ac.in

Abstract. Wire EDM is an unconventional machining processed for producing complicated profile on a hard material which is difficult in conventional cutting process. In WEDM heat affected zone is very minimum when compare to other unconventional cutting process. This distinct advantage made the WEDM to use in modern precision industries. In WEDM many process parameter which decides the quality of the machined component. In this study pulse on time, pulse off time, flushing pressure, wire tension, servo voltage and wire feed rate were selected as a process parameters. The effect of each parameter on material removal rate (MRR) was analyzed. Mathematical model was developed for material removal rate using regression analysis. The developed mathematical model is useful in predicting the response in the given range of input process parameter. Genetic algorithm was used to optimize the developed model. The optimized model would be the technical chart for the given material for the selected input parameter. The obtained results were experimentally verified.

1. Introduction

Wire EDM is an electro-thermal machining process particularly used for machining the hard materials with complex geometric shapes. Melting and vaporization is the material removal method in WEDM [1]. S. S. Mahapatra and Amar Patnaik, has developed a mathematical model to relate input process parameter and responses like MRR, Surface finish (SF) and kerf [2]. H.Singh et al. selected the input process parameters like pulse on time, gap voltage, peak current, pulse off time, wire tension and wire feed to analyse the MRR. They found that MRR increase with increase in the peak current and pulse on time [3]. Nihat Tosun et al analysed the effect of machining parameters on the MRR in wire EDM operations. The experiment was conducted by varying open circuit voltage, pulse duration, flushing pressure and wire speed. Machining parameters settings were determined by taguchi experimental design method [4]. Bijaya Bijeta Nayaket et al. have machined Inconel718 material with selected process parameter in EDM. Taguchi technique was used to conduct experiment. Pulse duration, part thickness, taper angle, wire speed, discharge current and wire tension were selected as a process parameter. Artificial neural network (ANN) model was developed to relate the process parameter and output responses [5].

J.Udaya Prakash, et al. have optimized the process parameters in WEDM for Aluminium alloy (A413) boron carbide hybrid composites material. The selected process parameter are gap voltage, pulse off time, wire feed, pulse on time, and percentage reinforcement. The observed responses are material removal rate and surface roughness. Taguchi’s L27 orthogonal array was used for the experimentation under different combination of parameters [6]. Amar Patnaik et al. used zinc coated
copper as electrode with the selected input process parameters like discharge current, dielectric flow rate, pulse frequency, pulse duration, wire speed and wire tension. By using selected factors maximization of material removal rate (MRR) and minimization of SR was done in WEDM process using taguchi method. Taguchi method was an effective technique to predict input process parameters for optimal process performance [7]. Genetic algorithm was an effective optimization technique used for WEDM machining process [8]. In this paper taguchi technique is used for modelling and GA is employed to optimize the MRR during WEDM.

2. Experimentation

The experiment is performed on Electra Spring cut 734 four axis Wire-EDM. The experiment is designed using Taguchi method. Totally 27 experiments conducted at various level of input parameter. As six input parameters namely current, pulse on, pulse off time, Servo voltage wire feed and fluid pressure are chosen for the experiments. Input parameters and their range is shown in table 1.

| S.No | Symbol | Input process parameter            | Levels |
|------|--------|------------------------------------|--------|
|      |        |                                    | I      | II     | III    |
| 1    | A      | Pulse on Time- Ton (μs)            | 110    | 115    | 120    |
| 2    | B      | Pulse off time T-off (μs)          | 40     | 45     | 50     |
| 3    | C      | Flushing Pressure (kgf/cm²)- Fp    | 8      | 10     | 12     |
| 4    | D      | Wire Tension (kgf)- Wt             | 550    | 750    | 950    |
| 5    | E      | Servo Voltage (volt)- Sv           | 15     | 20     | 25     |
| 6    | F      | Wire feed rate (m/min)- Wf         | 6      | 8      | 10     |

The input process parameters range is selected based on the trail run which conducted on the machine. Some of the parameter are kept constant due to limitation on the machine. Molybdenum wire electrode shown in figure 1 is used for to machine the work piece. It is reusable type wire.

![Figure 1. Molybdenum wire electrode.](image-url)
The fixed parameter for this study is shown in the table 2. Material removal rate is selected response process parameter and it is calculated by weighing the workpiece before and after machining with respect to time. Calculated MRR for the experiments are shown in table 3.

**Table 2.** Fixed parameters.

| S.No | Fixed parameter       | Set value                           |
|------|-----------------------|-------------------------------------|
| 1    | Wire material         | Molybdenum wire of diameter of 0.25 mm |
| 2    | Peak current          | 230 Amps                            |
| 3    | Pulse in peak voltage | 2                                   |
| 4    | Servo feed setting    | 250                                 |

**Table 3.** Experiments using L$_{27}$ Orthogonal array.

| Run | Ton | Toff | Fp | Wt | Sv | Wf | MRR  |
|-----|-----|------|----|----|----|----|------|
| 1   | 110 | 40   | 8  | 550| 15 | 6  | 6.5826|
| 2   | 110 | 40   | 8  | 550| 20 | 8  | 6.096 |
| 3   | 110 | 40   | 8  | 550| 25 | 10 | 5.7664|
| 4   | 110 | 45   | 10 | 750| 15 | 6  | 6.0711|
| 5   | 110 | 45   | 10 | 750| 20 | 8  | 5.7778|
| 6   | 110 | 45   | 10 | 750| 25 | 10 | 5.4864|
| 7   | 110 | 50   | 12 | 950| 15 | 6  | 5.6018|
| 8   | 110 | 50   | 12 | 950| 20 | 8  | 5.4668|
| 9   | 110 | 50   | 12 | 950| 25 | 10 | 4.978 |
| 10  | 115 | 40   | 10 | 950| 15 | 6  | 8.3965|
| 11  | 115 | 40   | 10 | 950| 20 | 8  | 7.748 |
| 12  | 115 | 40   | 10 | 950| 25 | 10 | 7.2169|
| 13  | 115 | 45   | 12 | 550| 15 | 6  | 7.029 |
| 14  | 115 | 45   | 12 | 550| 20 | 8  | 6.6949|
| 15  | 115 | 45   | 12 | 550| 25 | 10 | 6.338 |
| 16  | 115 | 50   | 8  | 750| 15 | 6  | 5.9778|
| 17  | 115 | 50   | 8  | 750| 20 | 8  | 5.777 |
| 18  | 115 | 50   | 8  | 750| 25 | 10 | 5.4474|
| 19  | 120 | 40   | 12 | 750| 15 | 6  | 8.5164|
| 20  | 120 | 40   | 12 | 750| 20 | 8  | 8.1123|
| 21  | 120 | 40   | 12 | 750| 25 | 10 | 7.9431|
| 22  | 120 | 45   | 8  | 950| 15 | 6  | 8.1194|
| 23  | 120 | 45   | 8  | 950| 20 | 8  | 7.8864|
| 24  | 120 | 45   | 8  | 950| 25 | 10 | 7.8596|
| 25  | 120 | 50   | 10 | 550| 15 | 6  | 7.6905|
| 26  | 120 | 50   | 10 | 550| 20 | 8  | 7.1651|
| 27  | 120 | 50   | 10 | 550| 25 | 10 | 6.9987|

2.1. Regression model

There are two different types of models are been used in regression analysis. One is linear regression and another one is multiple regressions. In Linear regression only one independent variable to predict
the outcome of Y. In multiple regression two or more independent variables is available to predict the outcome. Mathematical representation of each type of regression is given in the form equation in (1)&(2)

\[ Y = C_0 + C_1 X_1 + C_2 X_2 + \cdots + C_n X_n \]  

Where \( X_1, X_2, \ldots, X_n \) - attributes of the data set  
\( C_0, C_1, \ldots, C_n \) - coefficients  
\( Y \) - Response.

\[ Y = C_0 + C_1 X_1 + C_2 X_2 + C_3 X_1^2 + C_4 X_2^2 + C_5 X_1 \times X_2 \]  

Where \( X_1, X_2 \) - attributes of the data set,  
\( C_0 \) and \( C_1 \) - coefficients  
\( Y \) - response

2.2. MRR Regression Equation

To compute the classification accuracy three fold cross validation is used. The observed datasets are randomly divided into three sets. Two sets of observed data are used to train LSE-MRLM and to develop the model. Third set of data is taken for testing the developed model. The instances in each class in each set are randomly picked up. The each simulation is performed for 10 trials. The developed MRR equation (3) is shown below

\[ \text{MRR} = -2.1323 + 0.224568 \text{Ton} - 0.401748 \text{Toff} - 1.05715 \text{Fp} + 0.00286929 \text{Wt} - 0.0661178 \text{Sv} + 0.0276469 \text{Toff} \times \text{Fp} - 0.000206035 \text{Fp} \times \text{Wt} \]  

(3)

3. Genetic algorithm

The genetic algorithm is a technique for solving both constrained and unconstrained optimization problems. It is based on natural selection, the process that drives biological evolution.

The objective of this current research work is to maximize the MRR

\[ \text{MRR} = f(\text{Ton}_\text{Toff}_\text{Fp}_\text{Wt}_\text{Sv}_\text{Wf}) \]

Subject to constraints

\begin{align*}
110 & \leq \text{Ton} \leq 120 \\
40 & \leq \text{Toff} \leq 50 \\
8 & \leq \text{Fp} \leq 12 \\
550 & \leq \text{Wt} \leq 950 \\
15 & \leq \text{Sv} \leq 25 \\
6 & \leq \text{Wf} \leq 10 
\end{align*}

Where Ton, Fp, Toff, Wt, Wf and Sv are pulse on time, fluid pressure, pulse off time, wire tension, wire feed and servo voltage respectively. Parameters of genetic algorithm and their selected value shown in table 4. The input parameters limitation range assigned based on experimental setup. \( f \) denotes relation between MRR and six input parameters. For every iteration of Genetic algorithms, MRR values are predicted by regression models for a specified population size. The Genetic algorithm randomly generated a real valued population of possible input process parameter chromosomes. A new population for the subsequent generation is produced based on old population using different operator
functions. Optimization was carried out using MATLAB software. Obtained optimized value for selected range of process parameter is shown in table 5.

| Number of generations | 500 |
|------------------------|-----|
| population size        | 20  |
| crossover rate         | 0.8 |
| crossover mechanism    | Two point |
| mutation rate          | 0.01 |

### 4. Confirmation Experiment

In order to prove the output which is obtained from genetic algorithm confirmation experiments is conducted. The specific set of input parameter is given by the genetic algorithm is experimentally verified. The experiment is repeated for three times to obtain an average output of the performance.

| Process parameter | MRR | Error |
|-------------------|-----|-------|
| Ton   | Toff | Fp   | Wt  | Sv  | Wf  | Predicted | Experimental |
| 120   | 40   | 12   | 750 | 20  | 8   | 8.256     | 8.426        | 2.03%        |

### 5. Conclusions

In this research work mathematical model for MRR was developed using regression analysis for the given range of input process parameter. The following conclusion were made from the study,

- The developed MRR regression mathematical model results are close agreement with experimental values.
- For material removal rate, Pulse current is the most significant factor and followed by pulse current.
- Optimum process parameter was derived from genetic algorithm process. The obtained optimum parameters are Ton of 120, Toff of 40, Fp of 12, Wt of 750, Sv of 20 and Wf of 8.

### References

[1] K.H. Ho, S.T. Newman, S. Rahimifard and R. Allen, "State of art in wire electric discharge machining (WEDM)", International Journal of Machine Tools and Manufacture, Vol 44, pp.1247-1259, 2004.

[2] S. Silambarasan and G. Prabhakaran, "Optimization of WEDM process parameter using genetic algorithm, International Journal of Mechanical and Production Engineering Research and Development, vol 8(8), pp. 426-430, 2009.

[3] H. Singh and A. Singh, "Effect of Pulse On/Pulse Off Time On Machining Of AISI D3 Die Steel Using Copper And Brass Electrode In EDM", International Journal of Engineering and Science, vol.1(9), pp.19-22, 2012.

[4] C.Tosun, Cajun and H. Pihtili, "The effect of cutting parameters on wire crater sizes in wire EDM", International Journal of Advanced Manufacturing Technology. vol. 21(11), pp. 857–
865, 2003.

[5] B.B. Nayak and S.S. Mahapatra, "Optimization of WEDM process parameters using deep cryo-treated Inconel 718 as work materia", Engineering Science and Technology an International Journal, vol. 19(1), pp.161-170, 2016.

[6] J.Udayaprasak, T. V. Moomthry and J. Milton Peter, "Experimental Investigations on Machinability of Aluminium Alloy (A413)/Flyash/B4C Hybrid Composites Using Wire EDM" "Procedia Engineering", vol. 64, pp.1344-1353,2013.

[7] S. S. Mahapatra and Amar Patnaik, "Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method", International Journal of Advanced Manufacturing Technology, vol 34(9-10), pp.2006.

[8] P. Shandilya and A.Tiwari, "Artificial Neural Network Modeling and Optimization using Genetic Algorithm of Machining Process",Journal of Automation and Control Engineering, vol. 2(4), pp.348-352, 2014.