Engineering Science and Technology, an International Journal 18 (2015) 171–177

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: http://www.elsevier.com/locate/jestch

Full length article

WEDM process variables investigation for HSLA by response surface methodology and genetic algorithm

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ARTICLE INFO

Article history:
Received 6 September 2014
Received in revised form
5 November 2014
Accepted 5 November 2014
Available online 23 December 2014

Keywords:
Genetic algorithm
HSLA
Overcut
Response surface methodology
WEDM

ABSTRACT

Wire electric discharge machining (WEDM) is a thermo-electric spark erosion non-traditional type manufacturing process. The applications of WEDM have been found in aerospace and die manufacturing industries, where precise dimensions were the prime objective. This process is applied in case of processing difficult to machine material. Brass wire is used as an electrode and High strength low alloy (HSLA) steel as a work-piece during experimentation. The present research deals with the effect of process parameters on the overcut while machining the HSLA steel on WEDM. The mathematical model has been developed with the help of Response Surface Methodology (RSM). Further this model is processed with help of Genetic Algorithm (GA) to find out the optimum machining parameters. The percentage error between the predicted and experimental values lies in the range of ±10%, which indicates that the developed model can be utilized to predict the overcut values. The experimental plan was executed according to central composite design. The optimal setting of process parameters is pulse on-time-117 μs; pulse off-time-50 μs; spark gap voltage-49 V; peak current-180 A and wire tension-6 g; for minimum overcut, whereas at the optimal setting overcut is 9.9922 μm.

1. Introduction

Wire electrical discharge machining (WEDM) is a non-conventional machining process used for hard to cut conductive material. Wire EDM finds many applications; for instance, in the manufacturing of various press tools, dies and even electrodes used in other areas of EDM. Wire EDM is now widely used in the aerospace, automobile and medical industries, as well as in virtually all areas of conductive material machining. The mechanism of metal removal in WEDM constitutes the erosion of material due to spark discharge between tool electrode and workpiece, immersed in a liquid dielectric medium. The microprocessor also constantly maintains the gap between the wire and the workpiece, which varies from 0.025 to 0.05 mm. Some of the attempts [8–10] have been discussed by various authors. Pandey and Jilani [14] worked on the machining characteristics using distilled water, tap water and a mixture of both. They observed that the best machining rate was achieved by tap water. William and Rajurkar [22] reported that wire electrical discharge machine (WEDM) manufacturers and users aims to achieve higher machining rate with desired accuracy and minimum surface damage. The complex and random nature of the erosion process in WEDM requires the application of deterministic as well as stochastic techniques. Surface roughness profiles were studied with a stochastic modelling and analysis methodology to better understand the process mechanism. With the application of scanning electron microscopic (SEM) important features of WED machined surfaces are found out. Bhatti and Hashmi [2] found a manipulator for obtaining the intricate and complex shape with WEDM.

Scott et al. [16] investigated the effects of WEDM process parameters, particularly the spark cycle time and spark on-time on thin cross-section cutting of Nd–Fe–B magnetic material, carbon bipolar plate, and titanium. In addition, Garg et al. [6] studied the main effects of pulse on time and pulse off time; the quadratic effects of pulse on time, peak current, and servo voltage; and the interaction effect of pulse on time and servo voltage, as well as pulse on time and pulse off time, have significant effects on dimensional deviation during the machining of Ti 6–2–4–2 alloy on WEDM. Takahata and Gianchandani [21] studied the use of electrode arrays for batch EDM generation of micro-features. Scott

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Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2014.11.004

et al. [15] used a factorial design requiring a number of experiments to determine the most favourable combination of the WEDM parameters. They investigated that the discharge current, pulse duration and pulse frequency is the noteworthy process parameters affecting the metal removal rate and surface finish, while the wire speed, wire tension and dielectric flow rate have the least. Khanna and Singh [19] optimized the process parameters for cryogenic treated D-3 material for WEDM. They found that cutting rate decreases with increase in pulse width, time between two pulses and servo reference mean voltage. Cutting rate first decreases and then increases in wire mechanical tension. Sharma et al. [18] made the mathematical models for cutting speed and dimensional deviation using response surface methodology. Analysis of variance (ANOVA) has been utilized for the analysis of significant process parameters. Pulse on-time found to be the most significant factor for both response variables. Goswami and Kumar [7] investigated the surface integrity, material removal rate and wire wear ratio of Nimonic 80A using WEDM process. Taguchi Technique has been adopted for the planning of experiments, while for multi-response optimization, Grey Relational theory was utilized. Higher value of pulse off-time and lower value of pulse-on time is beneficial for a good surface quality.

Most of the researchers have worked on cutting rate, metal removal rate, surface finish, electrode wear and dimensional accuracy etc. But a comparatively less work has been reported on the modelling and analysis of overcut, which is the basic reason of dimensional deviations. There are three product quality issues like surface finish, overcut and radial cut. Out of these issues overcut is considered for the present research work, because overcut cannot be eliminated as it is inherent to WEDM process, but can be minimized by a proper selection of process parameters. In the present work, high strength low alloys steel is considered for machining on WEDM. The mathematical model has been developed using RSM and optimization has been carried using Genetic Algorithm.

2. Experimental set-up

The experiments were performed on Electronica Make Elektra Sprintcut 734 wire electric discharge machine tool as shown in Fig. 1. The fixed process parameters are as during experimentation:

- Workpiece: High strength low alloy steel
- Electrode (tool): 250 μm Diameter Brass wire
- Conductivity: 20 mho
- Cutting voltage (V): 80 V
- Die-electric temperature: 35 °C
- Injection pressure set point was at 7 kg/cm^2
- Peak voltage (VP): setting 2
- Servo feed: 2050 units

The investigation of significant control factors for WEDM process based on the quality of the machining are grouped in various categories. The control factors, their designated symbols and range are given in Table 1. The range of all the control factors is selected for the present study based on the results obtained from preliminary experiments [17]. The material used for experimentation is High Strength low alloy steel. The chemical composition of material is given in Table 2. The overcut (V) is shown as in Fig. 2 and is calculated as.

$$\text{Overcut}(V) = \frac{\text{Width of cut} - D}{2} \qquad (1)$$

Fig. 1. WEDM machine tool.

3. Experimental methodology

In this optimization of control factors two methodologies are used, one is Response Surface Methodology and other is Genetic Algorithm. These two methodologies are explained below.

3.1. Response surface methodology

Response Surface Methodology is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [3]. RSM has been applied for developing the mathematical models in the form of multiple regression equations for the quality characteristics of WEDM process. In applying the response surface methodology, the dependent parameter was viewed as a surface to which a mathematical model is fitted. For the development of regression equations related to various quality characteristics of WEDM process, the second order response surface has been assumed as:

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<j=2}^{k} b_{ii} x_i x_j + e_r \qquad (2)$$

This assumed surface Y contains linear, squared and cross product terms of parameters x_i's. In order to estimate the regression coefficients, a number of experimental design techniques are available. Also no replication is needed to find error mean square.

Table 1
Control factors, symbols and their ranges.

Control factors	Symbol	Range (machine units)
Pulse on time	T_{on} (μs)	111–117
Pulse off time	T_{off} (μs)	36–50
Spark gap voltage	SV (V)	30–50
Peak current	IP (A)	120–180
Wire tension	WT (grams)	6–10