AN APPROACH TO OPTIMIZATION OF PROCESS PARAMETERS IN WIRE ELECTRICAL DISCHARGE MACHINING FOR EN24 ALLOY STEEL

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ABSTRACT

With the development of mechanical industry, the demands for materials having high hardness, toughness, strength and impact resistance are increasing. Wire EDM machines are used to cut all conductive material of any hardness or toughness or those are difficult or impossible to cut with conventional methods. Wire electrical discharge machining process is a highly complex, time varying & stochastic process. The process output is affected by large no of input variables. Therefore a suitable selection of input variables for the wire electrical discharge machining (WEDM) process relies heavily on the operators technology & experience because of their numerous & diverse range. The problem of arriving at the optimum levels of the operating parameters has attracted the attention of the researchers and practicing engineers for a very long time. Metal removal rate (MRR), surface finish & cutting rate are sought to obtain precision work.

In this paper an approach is made to determine optimum input parameter setting for material EN24 Alloy Steel at which better material removal rate (MRR) and surface finish are achieved. Using Response Surface Methodology, significant machining parameters affecting the performance measures are identified as pulse peak current, pulse on time, and duty factor. The effect of each control factor on the performance measure is studied individually using the plots of signal to noise ratio. The study demonstrates that the WEDM process parameters can be adjusted so as to achieve better metal removal rate, surface finish, electrode wear rate.

Keywords: *WEDM, Process parameters, Response Surface Methodology*

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1. INTRODUCTION

Electrical discharge machining (EDM) is one of the most extensively used non-conventional, thermo-electric metal removal process which remove material from the workplace by a series of discrete spark between a work and a tool electrode immersed in a liquid dielectric medium. Electrical energy is used directly to cut the material in final shape. Melting and vaporization takes place by these electrical discharges. The minute a mounts of the work material is then ejected and flushed away by the dielectric medium. The sparks occur at high frequency, which continuously and effectively removes the work piece material by melting and evaporation. To initiate the machine process electrode and work piece are separated by a small gap known as 'spark gap' which results into a pulsed discharge causing the removal of material.

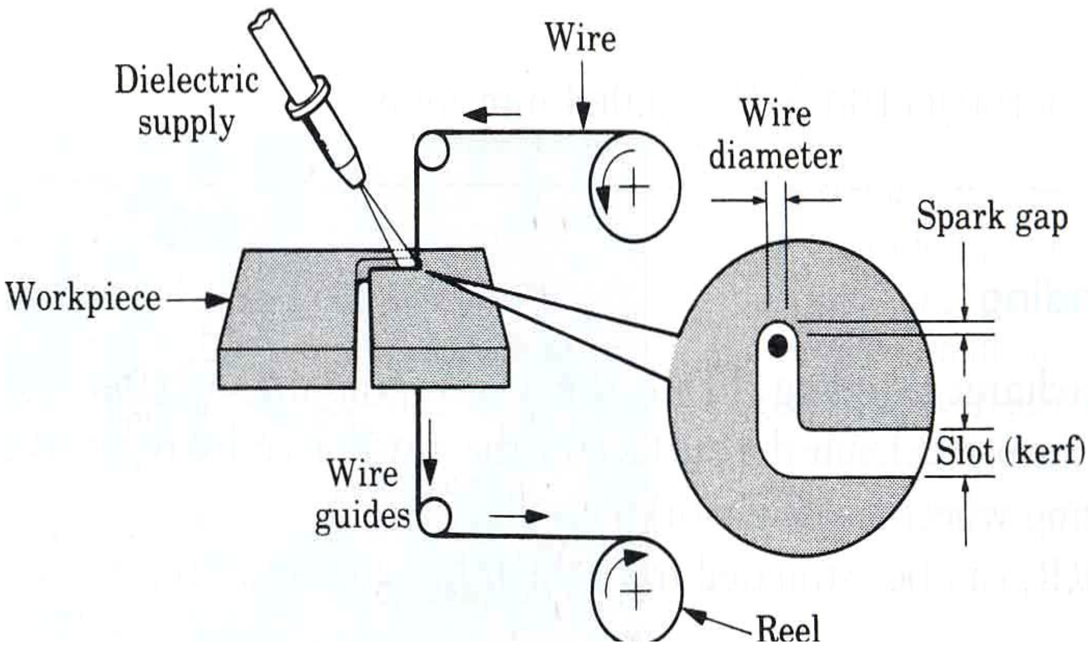
WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. The purpose of WEDM is to achieve better stability and higher productivity, higher machining rate with accuracy. A large number of variables are involved in the process; also the nature of the process is stochastic. Hence even a highly skilled operator is unable to perform the optimal performance. Although WEDM machines available today have some kind of process control, still selection is very tough to ensure optimal setting.

1.2 Basic Principal WEDM Process

Wire Electro-Discharge Machining (EDM) is a metal-working process whereby material is removed from a conductive work piece by electrical erosion. Wire EDM while not a new process, has rapidly become a key component in the manufacture of injection moulds, and metal stamping dies.

1. A wire electrode while under a positive charge is brought to within close proximity to a oppositely charged work piece.
2. Both the work piece and electrode are surrounded by de-ionized water which serves as a dielectric fluid insulator.

3. The electrical tension between the electrode and work piece eventually overcome the insulating properties of the dielectric medium and a spark jumps between them.
4. This spark is intensely hot (~12,000^{o}c) and literally vaporizes the material into fine positively charged ions and gases.
5. Several hundred thousand sparks per second are produced as the erosion takes place.
6. The particles are stripped from the gap area by high pressure flushing, and subsequently are stripped from the fluid through a de-ionization process.
7. A sufficient amount of OFF time must be given to remove these particles from the gap, to ensure that the EDM process can continue.
8. The distance between the electrode and work piece is referred to as the "Spark Gap" and is very closely maintained by state of the art servo control units.



As the electrode is moved along the path defined by NC program, the wire is continuously being spooled off, so in essence you are always cutting with a new surface on your electrode. This is necessary as the erosion that takes place on the work piece is also taking place on the electrode, that is to say, that the electrode is being eroded away. If at some point the amount of stock removed from the electrode becomes greater then the amount being removed from the steel, the wire electrode breaks and the discharge is stopped. These parameters are controlled by the machine controller unit, and on modern EDM controls, the correct power and voltage settings are automatically selected based on several factors; Material, Thickness, Accuracy, Surface Finish, among other variables.

2. OBJECTIVE OF THE PRESENT WORK

1. Experimental determination of the effects of the various process parameters viz pulse on time, pulse off time, spark gap set voltage, peak current, wire feed and wire tension on the performance measures like material removal rate, surface roughness in WEDM process
2. Optimization of the performance measures using Response Surface Methodology (RSM)
3. Modelling of the performance measures using response surface methodology (RSM)
4. Confirmation of the experiment using Design of Experiment Technique

3. LITERATURE SURVEY

3.1 Effect of process parameters on material removal rate in wire EDM [Singh, Garg]

The effect of various process parameters of WEDM like pulse on time (Ton), pulse off Time (Toff), gap voltage(SV), peak current (IP), wire feed (WF), wire tension (WT) have been investigated. The paper reveals their influence on the MRR of hot die steel (H-11). One variable at a time approach is used. The experiments were carried out on Electronica Sprint cut WEDM. Nihat Tosun et.al [8] investigated on the effects and optimization of machining parameters on the (cutting width) and material removal rate (MRR) in wire EDM operation. The experiments were conducted under various wire speed, open circuit voltage, pulse duration and dielectric flushing pressure. The design of experiment was done using Taguchi Method. A mathematical model was developed correlating the various wire EDM parameters like peak current, duty factor, wire tension and water present by Hewidy et al. [9]. The variations of above parameters were correlated with MRR.

3.2 Monitoring and control of micro-wire EDM :

In this paper presented by Mu-Tian Yan description about the development of a new monitoring and control system has been given. It contains a new pulse discriminating and control system has been given. It contains a new pulse discriminating and control system that identifies four major gap states categorized as –

- Open circuit
- Normal spark
- Arc discharge
- Short circuit

Following conclusions were drawn from the observations:

1. Discharge pulse can be classified into four pulse types by combination of some of the

time periods and gap voltage characteristics .The proportion of short circuit and sparking frequency can be used to monitor and evaluation of the gap condition.

2. If we set the long pulse interval and high table feed, it causes the gap to become smaller which results an increase in short ratio.

3. The increase of work piece thickness equivalent to MRR result in the formation of much debris in the spark gap leading to the increase of short ratio.

4. A pulse interval control strategy has been proposed according to the classification of discharge pulse to improve the abnormal machining conditions.

3.3 An Investigation on Wire Wear in WEDM :[Nihat Tosun , Can Cogun 2002]

In this study, the effect of cutting parameters on wire electrode wear was investigated experimentally in wire electrical discharge machining (WEDM). The experiments were conducted under different settings of pulse duration, open circuit voltage, wire speed and dielectric fluid pressure. Brass wire of 0.25 mm diameter and AISI 4140 steel of 10 mm thickness were used as tool and work piece material. It is found experimentally that the increasing pulse duration and open circuit voltage increase the wire wear ratio (WWR) whereas the increasing wire speed decreases it. The variation of work piece material removal rate and average surface roughness were also investigated in relation to the WWR. The variation of the WWR with machining parameters was modelled statistically by using regression analysis technique. The level of importance of the machining parameters on the WWR was determined by using analysis of variance (ANOVA) method.

3.4 Experimental study of wire electrical discharge machining of AISI D5 tool steel [Ahmet Hascalyk, Ulas Caydas 2004]

This paper presents an experimental investigation of the machining characteristics of AISI D5 tool steel in wire electrical discharge machining process. During experiments, parameters such as open circuit voltage, pulse duration, wire speed and dielectric fluid pressure were changed to explore their effect on the surface roughness and metallurgical structure. Optical and scanning electron microscopy, surface roughness and micro-hardness tests were used to study the characteristics of the machined specimens. Taking into consideration the experimental results, it was found that the intensity of the process energy does affect the amount of recast and surface roughness as well as micro-cracking, the wire speed and dielectric fluid pressure not seeming to have much of an influence.

3.5 Investigation of cylindrical wire electrical discharge turning of AISI D3 tool steel based on statistical analysis [Mohammad Jafar Haddad, Alireza Fadaei Tehrani 2008]

In this work, a surface roughness (Ra), roundness and material removal rate (MRR) study on the cylindrical wire electrical discharge turning (CWEDT) has been carried out. The material chosen in this case was AISI D3 tool steel due to its growing range of applications in the field of manufacturing tools dies and moulds as punch, tapping, reaming and so on in cylindrical forms. This study was made only for the finishing stages and has been carried out on the influence of four design factors: power, voltage, pulse off time and spindle rotational speed, over the three previous mentioned response variables. This has been done by means of the technique of design of experiments (DOE), which allows us to carry out the above-mentioned analysis performing a relatively small number of experiments. In this case, a 22 ×32 mixed full factorial design, has been selected considering the number of factors used in the present study. The resolution of this factorial design allows us to estimate all the main effects, factor interactions and pure quadratic effects of the four design factors selected to perform this study. For MRR, Ra and roundness regression models have been developed by using the response surface methodology (RSM).

3.6 Modelling and multi-response optimization of Inconel 718 on machining of CNC WEDM process [R.Ramakrishnan, L.Karunamoorthy 2008]

This paper describes the development of artificial neural network (ANN) models and multi response optimization technique to predict and select the best cutting parameters of wire electro-discharge machining (WEDM) process. To predict the performance characteristics namely material removal rate and surface roughness, artificial neural network models were developed using back-propagation algorithms. Inconel 718 was selected as work material to conduct experiments. A brass wire of 0.25mm diameter was applied as tool electrode to cut the specimen. Experiments were planned as per Taguchi's L9 orthogonal array. Experiments were performed under different cutting conditions of pulse on time, delay time, wire feed speed, and ignition current. The responses were optimized concurrently using multi response signal-to-noise (MRSN) ratio in addition to Taguchi's parametric design approach.

Analysis of variance (ANOVA) was employed to identify the level of importance of the machining parameters on the multiple performance characteristics. Finally, experimental confirmations were carried out to identify the effectiveness of this proposed method. A good improvement was obtained.

3.7 Parametric optimization during wire electrical discharge machining using response surface methodology [Pragya Shandilya, P.K.Jain 2012]

Present study has been made to optimise the process parameters during machining of SiCp/6061 Al metal matrix composite (MMC) by wire electrical discharge machining

(WEDM) using response surface methodology (RSM). Four input process parameters of WEDM (namely servo voltage (V), pulse-on time (TON), pulse-off time (TOFF) and wire feed rate (WF) were chosen as variables to study the process performance in terms of cutting width (kerf). The analysis of variance (ANOVA) was carried out to study the effect of process parameters on process performance. In addition mathematical models have also been developed for response parameter. Properties of the machined surface have been examined by the scanning electron microscopic (SEM). The experiments were conducted on the ECOCUT WEDM machine from Electronica India Pvt Ltd. A diffused brass wire of 0.25 mm diameter was used as the cutting tool. Aluminum (6061) based MMC, made by stir casting technique having 10% SiC particles (by weight) were used as the specimen. The specimens were of rectangular shape having a thickness of 6 mm. The deionized water was used as dielectric and its temperature was kept at 20ºC.

3.8 Wire electrical discharge machining applied to high-speed rotating work pieces [Eduardo Weingartner, Konrad Wegener, Friedrich Kuster 2012]

In order to evaluate the influence of high-speed rotating work pieces on wire electrical discharge machining (WEDM), single discharge experiments were carried out inside a grinding machine, in a self-designed wire electrical discharge dressing device (WEDD-device). The shape and size of eroded craters, measured on the work piece/anode, were found to be highly influenced by the applied relative speed. Based on the crater's shape, its radial expansion speed can be calculated and the slip of the plasma arc column can be measured. Additionally, it was found that the volume of eroded craters increases as relative speed is increased, indicating that higher melting efficiencies are achieved for higher relative speeds. Finally, an electro-thermal model is described and simulation results are discussed, which help to better understand the influence of relative speed on erosion.

4. EXPERIMENTAL SET UP

4.1 MACHINE TOOL

The experiment is to be carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Advanced Manufacturing Laboratory of Mechanical Engineering Department, N.I.T., Kurukshetra, Haryana, India. The WEDM machine tool has the following specifications:

Design:	Fixed column, moving table
Table size:	440 x 650 mm
Max. Work piece height:	200 mm

Max. Work piece weight: 500 kg

Main table traverse (X, Y): 300, 400 mm

Auxiliary table traverse (u, v): 80, 80 mm

Wire electrode diameter: 0.25 mm (Standard)

Generator: ELPULS-40 A DLX

Controlled axes: X Y, U, V simultaneous / independent

Interpolation: Linear & Circular

Least input increment: 0.0001mm

Least command input (X, Y, u, v): 0.0005mm

Input Power supply: 3 phase, AC 415 V, 50 Hz

Connected load: 10 KVA

Average power consumption: 6 to 7 KVA

4.2 WORK PIECE MATERIAL

The work material selected for the study was EN24 alloy steel with high tensile strength, shock resistance, good ductility and resistance to wear. The EN24 alloy steel is required to be heated to a temperature of 9000C to 9500 for hardening and followed by quenching in a oil medium. It is then tempered with temperature of 2000 to 2250 °C and obtains a final hardness of 45 to 55 HRC. EN24 is a medium-carbon low-alloy steel and finds its typical applications in the manufacturing of automobile and machine tool parts.

Chemical composition of the EN24 Steel is given in following table : -

Constituent	C	Si	Mn	Cr	Ni	Mo
% Composition	0.35 to 0.45	0.10 to 0.30	0.50 to 0.70	0.9 to 1.4	1.3 to 1.8	0.2 to

4.3 PROCESS PARAMETER

4.3.1 Electrode Parameter

1. Material of wire.
2. Diameter of wire.
3. Wire feed rate.
4. Wire tension.

4.3.2 Machine Parameter

Pulse on Time (Ton)

Pulse off Time (Toff)

Peak Current (IP)

Spark Gap Set Voltage (SV)

Gap Voltage (VP)

Dielectric flow rate

4.3.3 Performance Parameter

Material Removal Rate (MRR)

Surface Finish

5. REFERENCES

1. D. Scott, S. Boyina, K.P. Rajurkar, Analysis and optimisation of parameter combination in wire electrical discharge machining, Int. J. Prod. Res. 29 (11) (1991) 2189–2207.
2. K.P. Rajurkar, W.M. Wang, Thermal modeling and on-line monitoring of wire-EDM, J. Mater. Process Technol. 38 (1–2) (1993) 417–430.
3. Y.S. Tarng, S.C. Ma, L.K. Chung, Determination of optimal cutting parameters in wire electrical discharge machining, Int. J. Mach. Tools Manuf. 35 (129) (1995) 1693–1701.
4. T.A. Spedding, Z.Q. Wang, Parametric optimization and surface characterization of wire electrical discharge machining process, Precis. Eng. 20 (1) (1997) 5–15.
5. Y.S. Liao, J.T. Huang, H.C. Su, A study on the machining-parameters optimization of wire electrical discharge machining, J. Mater. Process. Technol. 71 (1997) 487–493.
6. Y.K. Lok, T.C. Lee, Processing of advanced ceramics using the wire-cut EDM process, J. Mater. Process. Technol. 63 (1–3) (1997) 839–843.
7. J.T. Huang, Y.S. Liao, W.J. Hsue, Determination of finish-cutting operation number and machining parameters setting in wire electrical discharge machining, J. Mater. Process. Technol. 87 (1999) 69–81.
8. M. Rozenek, J. Kozak, L. DabroVwki, K. LubkoVwki, Electrical discharge machining characteristics of metal matrix composites, J. Mater. Process. Technol. 109 (2001) 367–370.
9. N. Tosun, C. Cogun, An investigation on wire wear in WEDM, J. Mater. Process. Technol. 134 (3) (2003) 273–278.
10. N. Tosun, C. Cogun, H. Pihtili, The effect of cutting parameters on wire crater sizes in wire EDM, Int. J. Adv. Manuf. Technol. 21(2003) 857–865.

11. M.S. Chua, M. Rahman, Y.S. Wong, H.T. Loh, Determination of optimal cutting conditions using design of experiments and optimization techniques, Int. J. Mach. Tools Manuf. 33 (2) (1993) 297–305.
12. S.H. Lee, S.H. Lee, Optimization of cutting parameters for burr minimization in face-milling operations, Int. J. Prod. Res. 41 (3) (2003) 497–511.
13. W.H. Yang, Y.S. Tarng, Design optimization of cutting parameters for turning operations based on the Taguchi method, J. Mater. Process. Technol. 84 (1998) 122–129.
14. T.R. Lin, Optimization technique for face milling stainless steel with multiple performance characteristics, Int. J. Adv. Manuf. Technol. 19 (2002) 330–335.
15. P.J. Ross, Taguchi Techniques for Quality Engineering, 2nd ed., McGraw-Hill, New York, USA, 1996.
16. M.S. Phadke, Quality Engineering Using Robust Design, Prectice- Hall, Englewood Cliffs, New Jersey, USA, 1989.
17. J.P. Davim, C.A.C. Antonio, Optimization of cutting conditions in machining of aluminium metal matrix composites using a numerical and experimental model, J. Mater. Process. Technol. 112 (2001) 78–82.
18. N. Tosun, The effect of the cutting parameters on performance of WEDM, KSME Int. J. 17 (6) (2003) 816–824.