OPTIMIZATION OF PROCESS PARAMETERS IN MICRO WIRE EDM BY USING TAGUCHI‟S AND GENETIC ALGORITHMS

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ABSTRACT

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 operator's technology & experience because of their numerous & diverse range. WEDM is extensively used in machining of conductive materials when precision is of prime importance. Rough cutting operation in wire EDM is treated as challenging one because improvement of more than one performance measures viz. Metal removal rate(MRR), surface finish & cutting width (kerf) are sought to obtain precision work. In this paper an approach to determine parameters setting is proposed. Using taguchi's and Genetic Algorithm (GA) was employed to determine the values of optimal process parameters for the desired output value of wire electric discharge machining characteristics parameter design, 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, Metal removal rate, surface finish, taguchi method, Design of Experiment, S/N ratio, Electrode wear rate.*

INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface. 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.

LITERATURE REVIEW

WEDM is an essential operation in several manufacturing processes in some industries, which gives importance to variety, precision and accuracy. Several researchers have attempted to improve the performance characteristics namely the surface roughness, cutting speed, dimensional accuracy and material removal rate. But the full potential utilization of this process is not completely solved because of its complex and stochastic nature and more number of variables involved in this operation (Spedding and Wang, 1997; Scott et al., 1991). Scott et. al. (1991) developed mathematical models to predict material removal rate and surface finish while machining D-2 tool steel at different machining conditions. It was found that there is no single combination of levels of the different factors that can be optimal under all circumstances. Tarng et. al. (1995) formulated a neural network model and simulated annealing algorithm in order to predict and optimize the surface roughness and cutting velocity of the WEDM process in machining of SUS-304 stainless steel materials. Spedding and Wang (1997) attempted to model the cutting speed and surface roughness of EDM process through the response-surface methodology and artificial neural networks (ANNs). The authors attempted further to optimize the surface roughness, surface waviness and used the artificial neural networks to predict the process performance. Liao et. al. (1997) performed an experimental study using SKD11 alloy steel as the workpiece material and established mathematical models relating the machine performance like MRR, SR and gap width with various machining parameters and then determined the optimal parametric settings for WEDM process applying feasible-direction method of non-linear programming. Spedding and Wang (1997) attempted to optimize the process parametric combinations by modeling the process using artificial neural networks (ANN) and characterizing the WEDM machined surface through time series techniques. A feed-forward back-propagation neural network based on a central composite rotatable experimental design is developed to model the machining process. Optimal parametric combinations are selected for the process. The periodic component of the surface texture is identified and an autoregressive AR (3) model is used to describe its stochastic component. Huang et. al.(1999) investigated experimentally the effect of various machining parameters on the gap width, SR and the depth of white layer on the machined workpiece (SKD11alloy steel) surface. They adopted the feasible-direction non-linear programming method for determination of the optimal process settings. Hsue et. al. (1999) introduced a useful concept of discharge-angle Cθ and presented a systematic analysis for metal removal rate (MRR) in corner cutting. Discharge-angle Cθ and MRR dropped drastically to a minimum and then recovered to the same level of straight-path cutting sluggishly. The amount of the drop at the corner apex was dependent on the angle of the turning corner. The drastic variation of sparking frequency in corner cutting could be interpreted as the symptom of the abrupt change of MRR. The sudden increase of gap-voltage could also be interpreted as the result of abrupt MRR drop.

A study on the machining parameters optimization of WEDM.

Y.S Liao et al.[] devised an approach to determine machining parameter settings for wedm process .Based on the taguchi quality design and the analysis of variance (ANOVA), the significant factors affecting the machining performance such as MRR, gap width ,surface roughness ,sparking frequency ,average gap voltage, normal ratio(ratio of normal sparks to total sparks) are determined. By means of regression analysis, mathematical models relating the machining performance and various machining parameters are established. Based on the mathematical models developed, an objective function under the multi-constraint conditions is formulated. The optimization problem is solved by the feasible direction method, and the optimal machining parameters are obtained. Experimental results demonstrate that the machining models are appropriate and the derived machining parameters satisfy the real requirements in practice.

Experimental equipment

A WEDM machine developed by ITRI (Industrial Technology research institute) and CHMER company Taiwan was used as the experimental machine.

Work material: SKD11 alloy steels.
Electrode: Ø0.25 mm brass wire
Work piece height: 30 mm
Cutting length: 20 mm
Open voltage : 95V
Servo reference voltage : 10 V
Specific resitance of fluid : 1-3mA

Design of Experiment

Control factors each having 3 levels were chosen as follows:

1. pulse on time
2. pulse off time
3. table feed
4. wire tension
5. wire speed
6. flushing pressure

Machining performance measures studied

1. gap width
2. metal removal rate
3. surface roughness
4. discharging frequency
5. gap voltage
6. normal discharge frequency ratio.

The important conclusions that were drawn are:-

1. It was found that the table feed & pulse on time have a significant effect on the metal removal rate , the gap voltage & the total discharge frequency.
2. The gap width & surface roughness are mainly influenced by pulse on time.
3. Adjusting the table feed & ton is an appropriate strategy to control the discharging frequency for the prevention of wire breakage.
4. A larger table feed & a smaller ton are recommended as longer ton will result in higher value of Ra.
5. However this does not take place for a larger feed , although the table feed cannot be increased without constraints because of the risk of wire breakage

Study of the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide.

The aim of this project by Lee et al. [9] was to study the effect of machining parameters in EDM of tungsten carbide on the machining characteristics. The characteristics of EDM refer essentially to the output machining parameters such as material removal rate (MRR), relative wear ratio (RWR) and surface roughness (Ra). The machining parameters are the input parameters of the EDM process namely electrode material ,polarity , open ckt voltage , peak current, pulse duration, pulse interval & flushing pressure.

Experimental set up

M/C tool: - Roboform 40 m/c manufactured by charmilles technology.
Dielectric fluid: - EDM 22 mineral oil .
W/P material: - tungsten carbide
Electrode material: - graphite , copper , tungsten.

Conclusions drawn from the experiment

1. For all electrode materials the material removal rate increases with increasing peak current. graphite electrodes give the highest material removal rate followed by copper tungsten & then copper.
2. For all the three electrode materials the machined w/p surface roughness increases with increasing peak current. Copper exhibits the best performance with regard to surface finish followed by copper tungsten while graphite shows the poorest.
3. With the electrode as cathode & the workpiece as anode in EDM of tungsten carbide better machining performance can be obtained.
4. The material removal rate generally decreases with the increase of open ckt voltage whereas the relative wear ratio and machined workpiece surface roughness increase with the increase of open-ckt voltage.
5. The material removal rate decreases when the pulse interval is increased .both the relative wear ratio & the surface roughness have minimum values when varying the pulse interval, the minimum values occurring at the same value of pulse interval.
6. There is a maximum material removal rate with pulse duration at all current settings. The relative wear ratio increase with increase in pulse duration for all peak current settings. The increase is very pronounced at low pulse duration. The machined work piece surface roughness increases steadily with increasing peak current.

The Implementation of Taguchi Method on EDM Process of Tungsten Carbide.

In this paper, the cutting of Tungsten Carbide ceramic using electro-discharge machining (EDM) with a graphite electrode by using Taguchi methodology has been reported by Radzi et al.[6] . The Taguchi method is used to formulate the experimental layout, to analyse the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as peak current, voltage, pulse duration and interval time. It is found that these parameters have a significant influence on machining characteristic such as metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR). The analysis of the Taguchi method reveals that, in general the peak current significantly affects the EWR and SR, while, the pulse duration mainly affects the MRR.

EXPERIMENTAL METHOD :-
Electrical discharge machining condition

Work condition	Description
Electrode	Graphite, diameter 9 mm, Length 70 mm
Workpiece	Tungsten Carbide ceramic, square shape (100x100x7mm)
Voltage	120 to 200 V
Peak current	8 to 64 A
Pulse duration	1.6 to 50 µs
Interval time	3.2 to 800
Dielectric fluid	Kerosene
Technology	Blank/user tech

Conclusion drawn from the experimental results.

This paper has discussed the feasibility of machining Tungsten Carbide ceramics by EDM with a graphite electrode. Taguchi method has been used to determine the main effects, significant factors and optimum machining condition to the performance of EDM. Based on the results , we can conclude that, the peak current of EDM mainly affects the EWR and SR. The pulse duration largely affects the MRR.

Study of Wire Electrical Discharge Machined Surface Characteristics

The main goals of wire electrical discharge machine (WEDM) manufacturers and users are to achieve a better stability and high productivity of the process, i.e., 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.This paper presents the results of current investigations intothe characteristics of WEDM generated surfaces. Surface roughness profiles were studied by Williams et al.[3]. with a stochastic modeling and analysis methodology to better understand the process mechanism. Scanning electron microscopic (SEM) examination highlighted important features of WED machined surfaces. Additionally, energy dispersive spectrometry (EDS) revealed noticeable amounts of wire electrode material deposited on the workpiece surface.

EXPERIMENT

The machining experiment was performed on a Charmilles Robofil 100 5-axis *CNC* WEDM. Stratified wire in 0.25 mm diameter was used. The workpiece material was D2 tool steel. The preliminary goal of this research was to determine the effect of machining current on the surface roughness profiles. Current levels studied were 4, 8, 16 and 32 amperes (A). The workpiece was 3.8 cm in height. Four cuts 3.5 cm long were made under the different current settings. The final specimen for surface modeling was a rectangular slug 3.8 cm high x 3.5 cm wide x 0.5 cm thick. Each piece was marked to maintain the proper orientation before the wire cut it off. Surface roughness profiles were acquired in both the horizontal and vertical directions with a Mahr Perthen Perthometer (stylus radius 5 #m). It was obvious during the actual machining that the different maximum current settings were having a direct impact on the spark energy and, therefore, the machining rate. The specimen machined at 32 A was cut at a rate of 15-18 cm/hour while the machine cut at 5 cm/hour at 4 A. These values were read directly from the CNC control screen on the position page which monitors the generator. In order to realize the full potential of the wire electrical discharge machining (WEDM) process and to raise its scientific knowledge base, it was necessary to model and characterize WEDM generated surfaces. Results of this study led to the following conclusions.

1. An ARMA (4,3) model was found to be adequate to describe the WEDM surface. This is a higher model than that required for cavity sinking EDM.
2. Wavelength decomposition of WEDM surface profiles has shown no significant difference due to direction. Additionally, the power of the characteristic roots has linked the discharge energy to changes in the surface structure.
3. Scanning electron microscope (SEM) photographs showed that the higher peak current resulted in a rougher work piece surface.
4. Energy dispersive spectrometry (EDS) revealed that some amount of the wire electrode material from WEDM gets deposited onto the workpiece surface.

DESIGN OF EXPERIMENT

1. As per the taguchi quality design concept L9 orthogonal array table was arbitrarily chosen to study optimization process.
2. Three control factors were chosen each at 3 levels
   A- Pulse on time (µs)
   B- duty factor = (pulse on time/(pulse on time + pulse of time))
   C- pulse peak current (A)
3. Three response parameters were measured
   1. MRR(g/min) (Metal removal rate)
   2. EWR(%) (Electrode wear rate)
   3. Ra (µm) (Surface roughness)

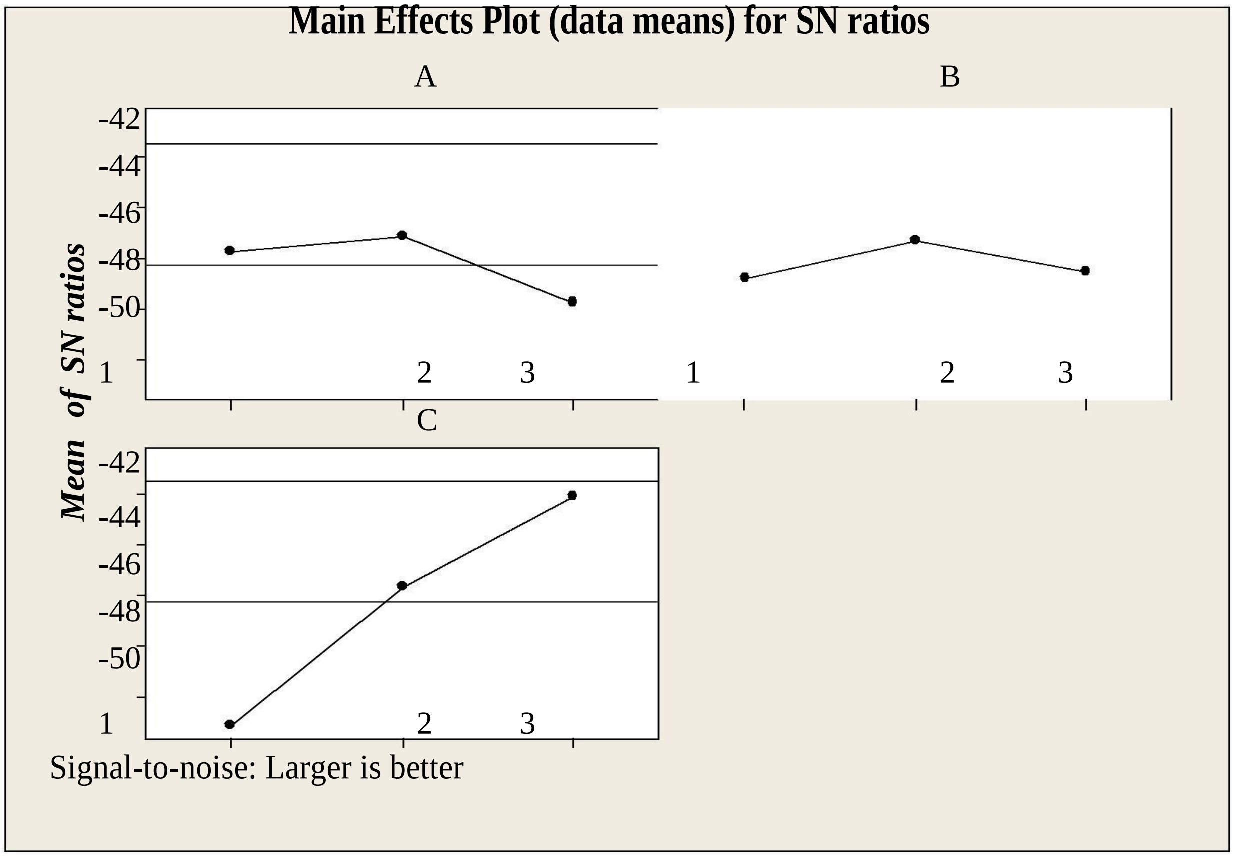
Table 2 : Machining parameters & their levels

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
A	Pulse on time	µs	5	100	200
B	Duty factor		0.2	0.4	0.6
C	Pulse peak current	A	1	5	7

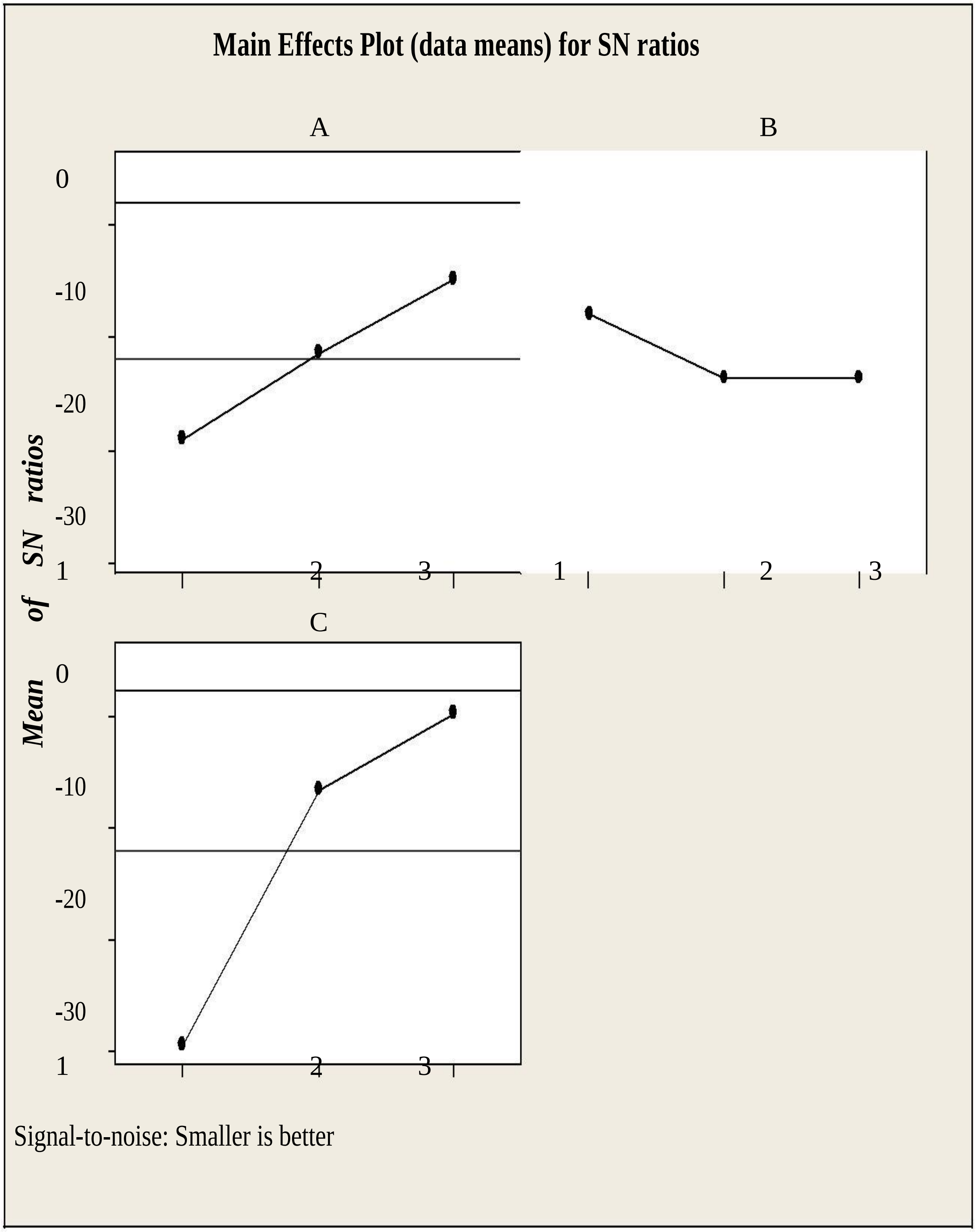
Table ˆ. Experimental results

A	B	C	MRR	EWR	Ra
1	1	1	0.0024	29.896	3.01
1	2	2	0.0058	5.253	2.78
1	3	3	0.0097	4.897	3.45
2	1	2	0.0066	2.345	2.95
2	2	3	0.0087	0.765	2.98
2	3	1	0.0029	28.906	2.5
3	1	3	0.0059	0.234	2.12
3	2	1	0.0031	28.865	2.56
3	3	2	0.0037	0.789	2.01

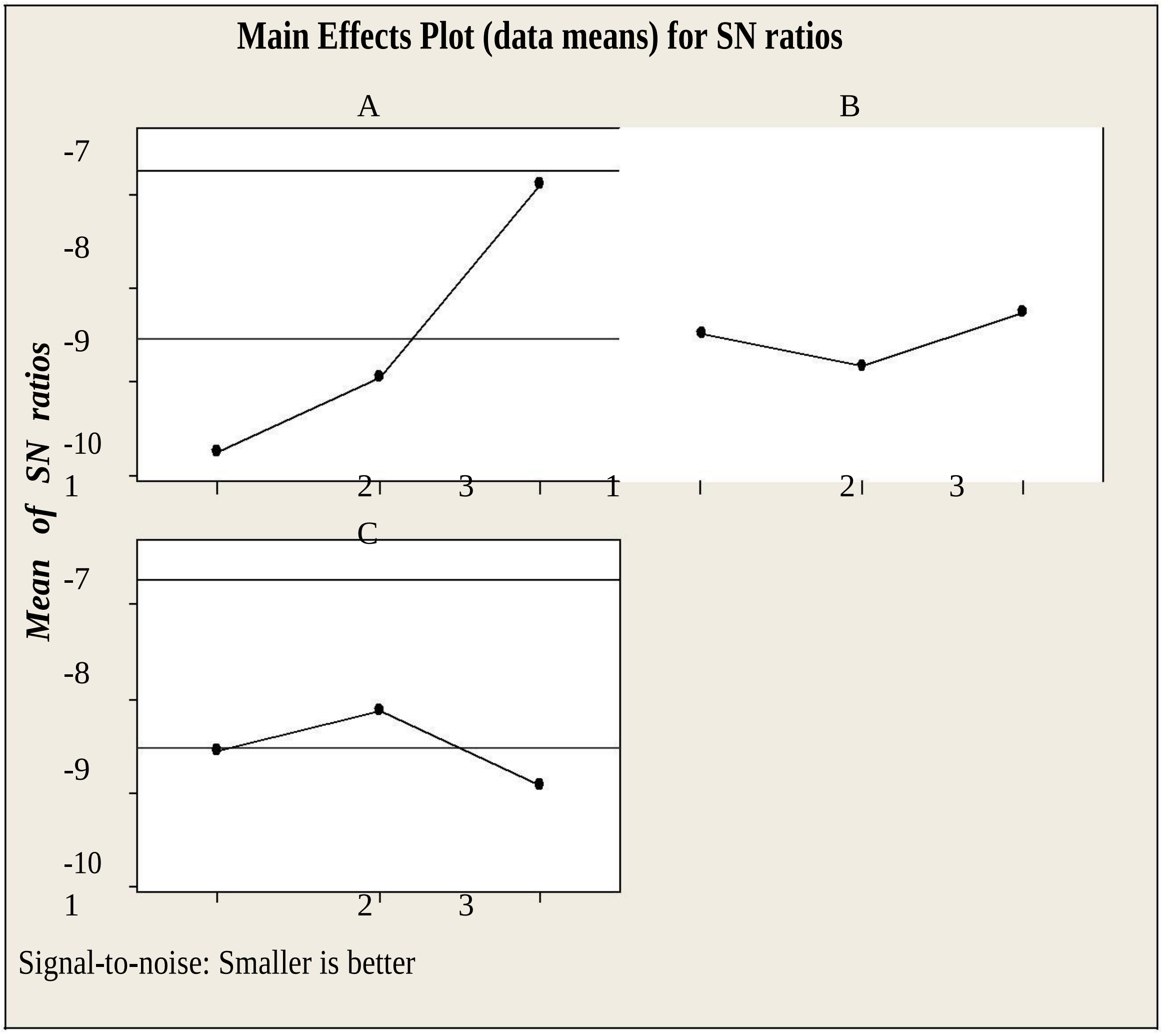
Graph 1 : Effect of Control factors On MRR



Graph 2 : Effect of Control Factor on EWR



Graph 3: Effect of Control factor on Surface Roughness



RESULTS & DISCUSSIONS

1. It can be seen from the graph 1 for MRR to be maximum factor A ,B has to be at level 2 & factor c has to be at level 3.
2. Pulse peak current is the most critical factor affecting MRR& duty factor is the least significant parameter.
3. For minimum EWR factor AC has to be at level 3 & factor B has to be at level 1.
4. Pulse peak current is the most critical factor affecting EWR& duty factor is the least significant parameter.
5. For minimum surface roughness factor A, B has to be at level 3 & factor C has to be at level 2.
6. Pulse on time is the most critical factor affecting surface roughness & duty factor is the least significant parameter.

CONCLUSION

Optimization of µ-WEDM process parameters is very much essential as this is a expensive and widely used. In this work, a unique approach for modeling and optimization of µ-WEDM process is developed using theoretical modeling by considering thermo physical properties. ANOVA based regression models are used to check the adequacy of the proposed model and conformability by GA. The results indicate that the proposed models have good conformability to the real processes. An optimization method based on Genetic Algorithm has been employed to determine the proper process parameter values for any given set of desired machining characteristics. Computational results show that the proposed GA method could efficiently and accurately determine machining parameters for any desired process output specification. Modeling and optimization approach developed in this work can provide as a very effective tool for enhancing accuracy and capability of the µ-WEDM process.

The model shows excellent prediction accuracy.

1. It is interesting to note that optimal settings of parameters for MRR, EWR & Surface roughness are quite different & poses difficulty to achieve the goals of all objectives.
2. An attempt was made to determine important machining parameters for performance measures like MRR, EWR & Surface roughness &separately in the Micro WEDM process.
3. Factors like discharge current, pulse on time & their interactions have been found to play a significant role in rough cutting operations.
4. Lastly it can be concluded that in order to optimize for all the three objectives i,e MRR, EWR & Surface roughness simultaneously , mathematical models using the nonlinear regression model has to be developed

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