OPTIMIZATION OF PROCESS PARAMETERS OF MICRO WIRE EDM

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In

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by

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CERTIFICATE

This is to certify that this report entitled, "**OPTIMIZATION OF PROCESS PARAMETERS OF MICRO WIRE EDM**" submitted by Ricky Agarwal in partial fulfillment for the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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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 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 .

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Chapter 1

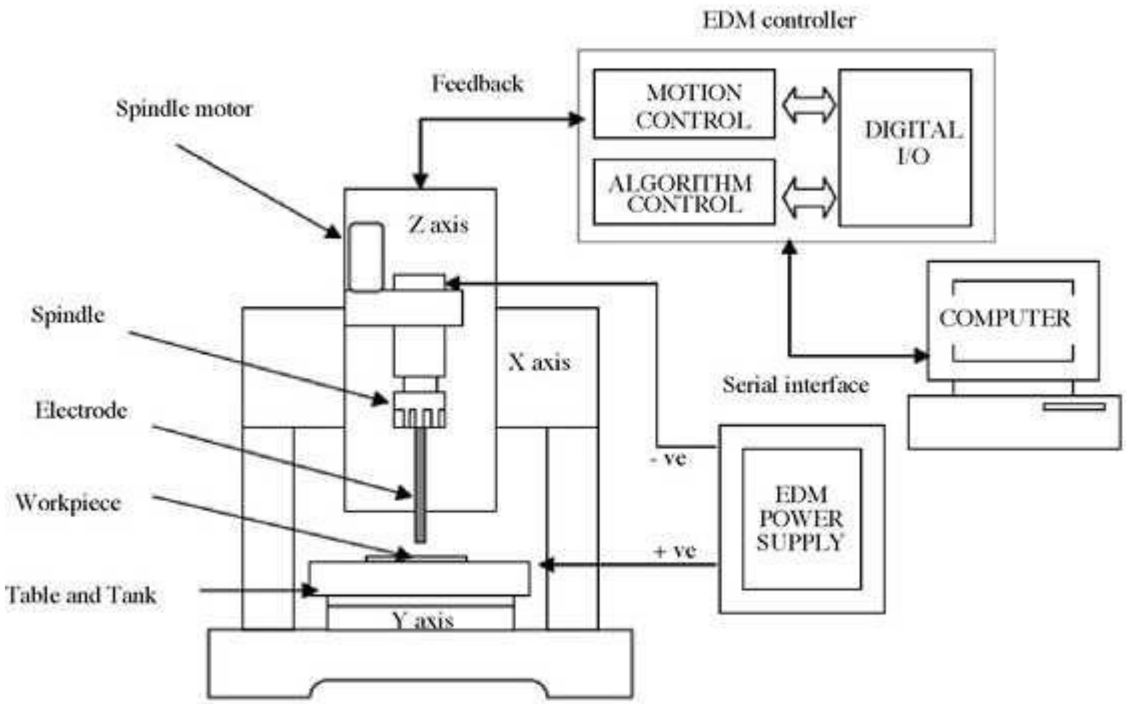
Introduction

Electrical discharge machining (EDM) is a nontraditional, thermoelectric process which erodes material from the workpiece by a series of discrete sparks between a work and tool electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric. The sparks occurring at high frequency continuously & effectively remove the workpiece material by melting & evaporation. The dielectric acts as a deionising medium between 2 electrodes and its flow evacuates the resolidified material debris from the gap assuring optimal conditions for spark generation . In micro wire edm metal is cut with a special metal wire electrode that is programmed to travel along a preprogrammed path. A wire EDM generates spark discharges between a small wire electrode (usually less than 0.5 mm diameter) and a workpiece with deionized water as the dielectric medium and erodes the workpiece to produce complex two- and three dimensional shapes according to a numerically controlled (NC) path.

The wire cut EDM uses a very thin wire 0.02 to 0.3 mm in diameter as an electrode and machines a workpiece with electrical discharge like a bandsaw by moving either the workpiece or wire . erosion of the metal utilizing the phenomenon of spark discharge that is the very same as in conventional EDM . The prominent feature of a moving wire is that a complicated cutout can be easily machined without using a forming electrode .Wire cut EDM machine basically consists of a machine proper composed of a workpiece contour movement control unit (NC unit or copying unit), workpiece mounting table and wire driven section for accurately moving the wire at constant tension ; a machining power supply which applies electrical energy to the wire electrode and a unit which supplies a dielectric fluid (distilled water) with constant specific resistance.

The main goals of WEDM manufacturers and users are to achieve a better stability and higher productivity of the WEDM process, i.e., higher machining rate with desired accuracy and minimum surface damage. However, due to a large number of variables and the stochastic nature of the process, even a highly skilled operator working with a state-of-the-art WEDM is unable to achieve the optimal performance and avoid wire rupture and surface damage as the machining progresses. Although most of the WEDM machines available today have some kind of process control, still selecting and maintaining optimal settings is an extremely difficult job. The lack of machinability data on conventional as well as advanced materials, precise gap monitoring devices, and an adaptive control strategy that accounts for the time-variant and stochastic nature of the process are the main obstacles toward achieving the ultimate goal of unmanned WEDM operation.

Fig 1. Micro EDM Experimental Set up



1..1 Features of Micro Wire EDM process

1. Forming electrode adapted to product shape is not required.
2. Electrode wear is negligible.
3. Machined surfaces are smooth .
4. Geometrical & dimensional tolerances are tight.
5. Relative tolerance between punch & die is extremely high & die life is extended.
6. Straight holes can be produced to close tolerances.
7. EDM machine can be operated unattended for long time at high operating rate.
8. Machining is done without requiring any skills.
9. Any electrically conductive material can be machined irrespective of its hardness & strength.
10. EDM allows the shaping of complex structures with high machining accuracy in the order of several micrometres and achievable surface roughness Rz=0.µm.
11. It proves to be a competitive method for ceramic processing because of the abilities to provide accurate, cost-effective and flexible products.

1.2 Objectives

There are many machining parameters affecting the wire EDM machine performance and the real mathematical models between machining performance and machining parameters are not easy to be derived because of the complex machining mechanism . The objectives are as follows:-

1. To achieve the shortest machining time whilst at the same time satisfying the requirements of accuracy and surface roughness.

2.To discuss the cause – effect relationship of machining parameters & machine performance in WEDM.

3.To determine significant parameters affecting the machining performance.

4.To establish the the mathematical models relating the machining performance & machining parameters by regression & correlation analysis.

5.Finally the optimal machining parameters are obtained under the constraints & requirements.

1.3 Process parameters of Micro Wire EDM process

PARAMETERS	RANGE
1. Frequency	0-200 KHz
2.Pulse width	1-10 µs
3. gap % of voltage	60-100%
4. gain	0-100
5. pulse peak current	40A
6. output voltage	60-250V
7. Dwell time	0-20s
8. polarity	+/-
9.hole diameter	0.05 -1 mm
10. spindle speed	100-1000 rev/min

Machine parameters

1. table feed
2. pulse on time
3. pulse off time
4. flushing

Wire parameters

1. material of wire
2. diameter of wire
3. wire speed
4. wire tension

Chapter 2

Literature review

2.1. A study on the machining parameters optimization of WEDM.

Y.S Liao et al.[1,5] 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

2.2.Monitoring & control of the micro wire EDM PROCESS

In this paper an attempt was made by Tian et al.[8] towards process monitoring and control of micro wire EDM process by developin g a new pulse discrimination & control system . This system functions by identifying 4 major gap states classified as open ckt, normal spark, arc discharge,and short ckt by observing the characteristics of gap voltage waveforms. The influence of pulse interval , machining feed rate, and workpiece thickness on the normal ratio , arc ratio & short ratio. It could be concluded from the experiment that a longer pulse interval would result in increase of short ratio at constant machining feed rate.A high machining federate as well as increase of work piece height results in increase of short ratio.

To achieve stability in machining a control strategy is proposed by regulating the pulse interval of each spark in real time basis by analyzing the normal ratio , arc ratio & short ratio. Experimental results show that the developed pulse discrimination system & control strategy is very useful in reducing both arc discharge & short sparking frequency which are undesirable during the process. Also with this process monitoring a stable machining under the condition where the instability of machining operation is prone to occur can be achievable.

Following conclusions were drawn from the experiment.

1.Discharge pulses can be classified in to four pulse types by combining some of the time periods and gap voltage characteristics . The proportion of short ckts & the sparking frequency can be employed to monitor & evaluate the gap condition .

2. The setting of long pulse interval & high table feed cause the gap to become smaller & thus contribute to an increase of the short ratio.

3. The increase of workpiece thickness results in much debris in the spark gap & thereby leading to an increase of short ratio.

4. According to the classification of discharged pulses , a pulse interval control strategy has been proposed to improve the abnormal machining condition . Experimental results not only verify the effectiveness of the proposed control method they also indicate that the developed pulse discriminating & control system is capable of achieving stable machining under the condition where there exists an unexpected disturbance during machining.

2.3 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 workpiece surface roughness increases steadily with increasing peak current.

2.4 Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method

In this paper improvement of more than one machining performance measures are sought by Pattnaik et al.[3]. In rough cutting operation objectives are three fold High MRR, high surface finish & low cutting width (kerf) . Using taguchi's parameter design significant machining parameters affecting the performance are identified as discharge current , pulse duration, pulse frequency, wire speed , wire tension & dielectric flow. In this study the relationship between control factors & responses like MRR , SF and kerf are established by means of non linear regression analysis resulting in a valid mathematical model .

Experimental method

- Work piece –a block of D2 Tool steel with 200x25x10 mm size
- Electrode (cathode) - 0.25 mm dia brass wire
- Cutting length -100 mm with 10 mm depth along longer length
- Experimental M/C – ROBOFIL 100 high precision 5 axis CNC WEDM
- As per the taguchi quality design concept a L 27 orthogonal array table was chosen for the experiments.
- The behaviour of six control factors A,B,C,D,E,F and two interactions AXB and AXF are to be studied .
- Three performance measures in the rough cutting phase are investigated.

2.5 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 :-

Table 1 : 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.

2.6 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 workpiece surface.

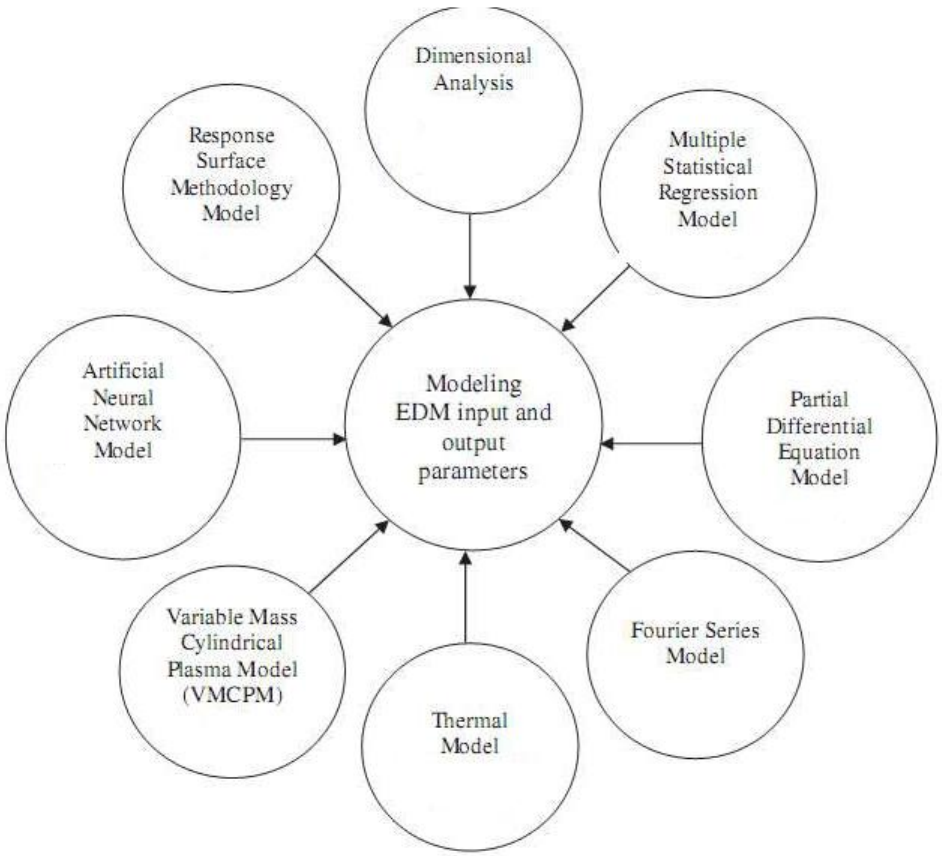
4. Energy dispersive spectrometry (EDS) revealed that some amount of the wire electrode material from WEDM gets deposited onto the workpiece surface.

2.7 Study Of Wire Breaking Process and Monitoring of WEDM

Wire rupture in the Wire Electrical Discharge Machining (WEDM) process is a serious problem to manufacturers. A new computer-aided pulse discrimination system based on the characteristics of voltage waveform during machining was developed in this paper by Liao et al [1,5] . With the use of this system, a large amount of sparking frequency data during wire rupture process and under normal working conditions were collected and analyzed. Two symptoms of wire rupture were identified: the excess of arc sparks, and a sudden rise of the total sparking frequency. The governing mechanisms of these two types of wire rupture were found from the SEM and EDAX analyses of the ruptured wire electrode. Furthermore, an index to monitor wire breaking was identified, and its relationships with the metal removal rate and machining parameters were found. Based on the results obtained
in the paper, a control strategy to prevent wire from rupturing while at the same time improving the machining speed is proposed.

Conclusion
This paper develops a new computer-aided pulse discrimination system which can be employed to collect the sparking frequency of pulse trains for a long period of time. Thus, the variations of pulse frequency can be precisely recorded. Two types of wire rupture are classified according to the observation of cross section of ruptured wire by SEM, and
the symptoms of pulse trains during wire rupture process. An index to monitor the wire rupture is found. In addition, the relationships between this index, metal removal rate and machining parameters are found, and a control strategy to prevent wire rupture while improving the machining speed is proposed. The implementation of the proposed control strategy is under way.

Fig 2 Theoretical Model Available In Literature for Simulating the Input and Output Model



Chapter 3

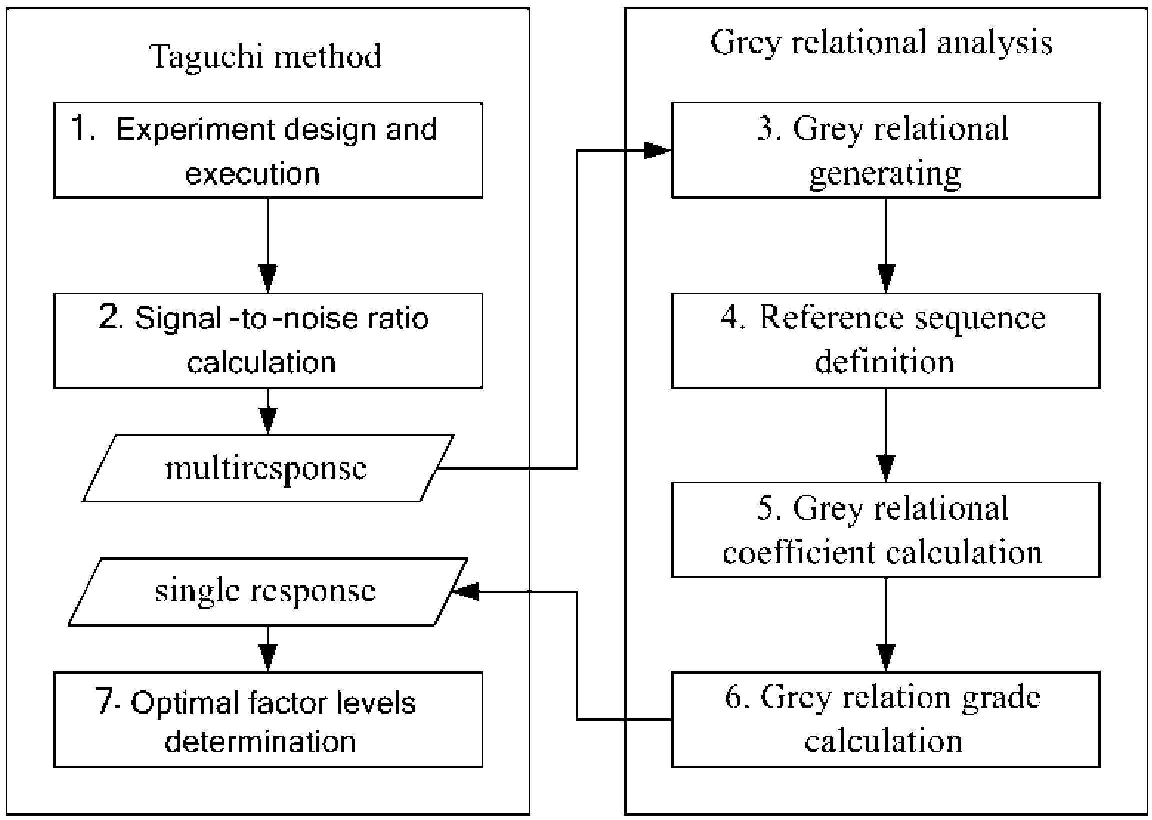
Optimization Techniques

3.1.**GREY BASED TAGUCHI METHOD**:-Genichi Taguchi, a Japanese scientist, developed a technique based on OA of experiments. This technique has been widely used in different fields of engineering to optimize the process parameters . The integration of DOE with parametric optimization of process can be achieved in the Taguchi method. An OA provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios,which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a small number (minimum experimental runs) of experiments.

OA and S/N ratios are used to study the effects of control factors and noise factors and to determine the best quality characteristics for particular applications . The optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors . However, originally, Taguchi method was designed to optimize single-performance characteristics . Optimization of multiple performance characteristics is not straightforward and much more complicated than that of single-performance characteristics.To solve the multiple performance characteristics problems,the Taguchi method is coupled with grey relational analysis.Grey relational analysis was first proposed by Deng in 1982 to fulfill the crucial mathematical criteria for dealingwith poor, incomplete, and uncertain system . This grey-based Taguchi technique has been widely used indifferent fields of engineering to solve multi-response optimization problems.

The procedure of the grey-based Taguchi method is shown in Figure 1.In Figure 1, steps 1, 2 and 7 are general procedures of the Taguchi method and steps 3 to 6 are the procedure of GRA

Fig 3. Procedure of the grey-based Taguchi method.



Step 1: Experiment design and execution

Classical process parameter design is complex and not easy to use (Fisher 1925).A large number of experiments have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments (Lin and Lin 2002). Therefore, the first step of the proposed procedure of simulation optimization is to select an appropriate orthogonal array in which every row represents a simulation scenario. The simulation runs are then executed by following the experimental structure of the selected orthogonal array.

Step 2: Signal-to-noise ratio calculation

The Taguchi method aims to find an optimal combination of parameters that have the smallest variance in performance. The signal-to-noise ratio (S/N ratio, η) is an effective way to find significant parameters by evaluating minimum variance.A higher S/N ratio means better performance for combinatorial parameters. Let η_{ij} be the S/N ratio for the response *j* of scenario *i* and let v_{ijk} be the simulation result for the response *j* of scenario *i*, in the *k*th replication; *r* is the total number of replications. The definition of the S/N ratio can then be defined as

$$\eta_{ij} = -10\log\left(\frac{1}{r}\sum_{k=1}^{r}\frac{1}{v_{ijk}^{2}}\right) \qquad (1)$$

$$\eta_{ij} = -10\log\left(\frac{1}{r}\sum_{k=1}^{r}v_{ijk}^{2}\right) \qquad (2)$$

Equation (1) is used for the 'larger-the-better' responses and Equation (2) is used for the 'smaller the- better' responses. Besides using the S/N ratio, some authors (Fung 2003, Lin and Lin 2002) use the mean of the simulation results of all the replications for optimization. The present research therefore also optimized the mean value for comparison. After calculating S/N ratios and mean values for each response of all simulation scenarios, the proposed grey-based Taguchi method then views the multi-response problem as a MADM problem. Different terminology is commonly used to describe MADM problems, and in the following description some terms have been adjusted to conform with usual MADM usage. Thus 'response'was replaced by 'attribute', and 'scenario'was replaced by 'alternative'in the following.

Step 3: Grey relational generating

When the units in which performance is measured are different for different attributes, the influence of some attributes may be neglected. This may also happen if some performance attributes have a very large range. In addition, if the goals and directions of these attributes are different, this will cause incorrect results in the analysis (Huang and Liao 2003). It is thus necessary to process all performance values for every alternative into a comparability sequence, in a process analogous to normalization. This processing is called grey relational generating in GRA. For a MADM problem, if there are *m* alternatives and *n* attributes, the *i*th alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, \ldots, y_{ij}, \ldots, y_{in})$, where y_{ij} is the performance value of attribute *j* of alternative *i*. The term Y_i can be translated into the comparability sequence $X_i = (x_{i1}, x_{i2}, \ldots, x_{ij}, \ldots, x_{in})$ by the use of one of Equations (3)–(5), where

$\overline{y}_j = Max\{y_{ij}, i = 1, 2, \ldots, m\}$ and $\underline{y}_j = Min\{y_{ij}, i = 1, 2, \ldots, m\}$.

$$x_{ij} = (y_{ij} - \underline{y}_j)/(\overline{y}_j - \underline{y}_j) \qquad (3)$$

$$x_{ij} = (\overline{y}_j - y_{ij})/(\overline{y}_j - \underline{y}_j) \qquad (4)$$

$$x_{ij} = 1 - |y_{ij} - y_j^*| / \max\{\overline{y}_j - y_j^*, y_j^* - \underline{y}_j\} \qquad (5)$$

Equation (3) is used for larger-the-better attributes, Equation (4) is used for smaller-the-better attributes, and Equation (5) is used for 'closer-to-the desired-value-y_j^* -the-better' attributes. Note that the S/N ratio that was calculated in step 2 is a larger-the-better attribute. Therefore, the proposed grey-based Taguchi method only uses Equation (3) for grey relational generating.

Step 4: Reference sequence definition

After the grey relational generating procedure, all performance values will be scaled into [0, 1]. For an attribute j of alternative i, if the value x_{ij} that has been processed by grey relational generating is equal to 1, or nearer to 1 than the value for any other alternative, the performance of alternative i is the best one for attribute j . Therefore, an alternative will be the best choice if all of its performance values are closest to or equal to 1. However, this kind of alternative does not usually exist. This article defines the reference sequence X_0 as $(x_{01}, x_{02}, \ldots, x_{0j}, \ldots, x_{0n}) = (1, 1, \ldots, 1, \ldots, 1)$, and then aims to find the alternative whose comparability sequence is the closest to the reference sequence.

Step 5: Grey relational coefficient calculation

The grey relational coefficient is used to determine how close x_{ij} is to x_{0j} . The larger the grey relational coefficient, the closer x_{ij} and x_{0j} are. The grey relational coefficient can be calculated by

$\gamma(x_{0j}, x_{ij}) = (\Delta_{min} + \xi\Delta_{max}) / (\Delta_{max} + \xi\Delta_{max})$ i= 1, 2, . . . , m j = 1, 2, . . . , n (6)

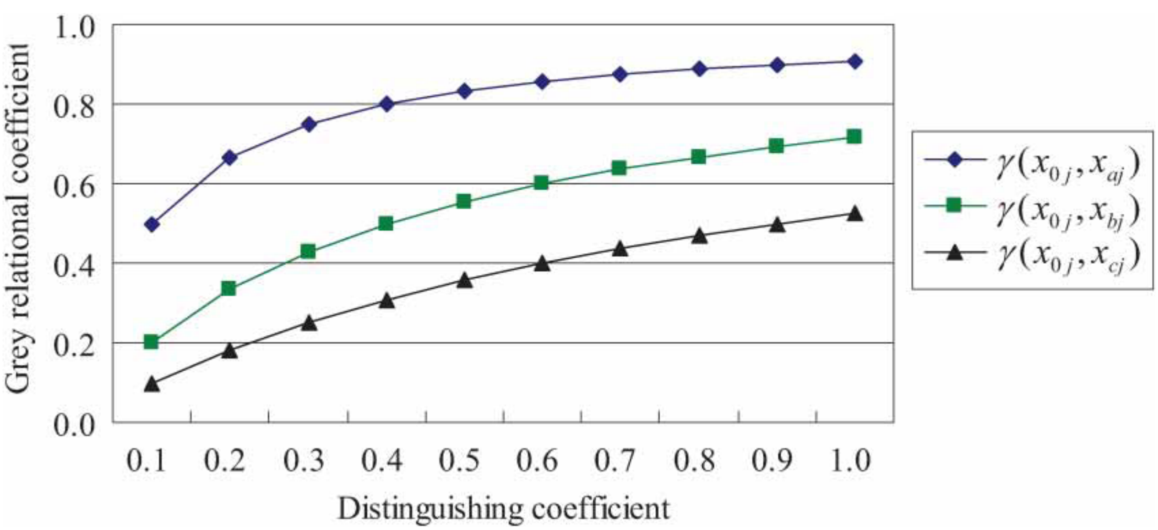


Fig 4. Relationship between distinguishing coefficient and grey relational coefficient.

In Equation (6), $\gamma\ (x_{0j}, x_{ij})$ is the grey relational coefficient between x_{ij} and x_{0j} and

$\Delta_{ij} = | x_{0j} - x_{ij}|$

$\Delta_{min} = \min\{ \Delta_{ij}\ \ i=1, 2, \ldots, m; j = 1, 2, \ldots, n\}$

$\Delta_{max} = \max \{ \Delta_{ij}\ \ i=1, 2, \ldots, m; j = 1, 2, \ldots, n\}$

ζ is the distinguishing coefficient, $\zeta \in [0, 1]$

The purpose of the distinguishing coefficient is to expand or compress the range of the grey relational coefficient. For example, take the case where there are three alternatives, *a*, *b* and *c*. If $\Delta_{aj} = 0.1$, $\Delta_{bj} = 0.4$, and $\Delta_{cj} = 0.9$, for attribute *j* , alternative *a* is the closest to the reference sequence After grey relational generating using Equations (3)–(5), Δ_{max} will be equal to 1 and Δ_{min} will be equal to 0. Figure 2 shows the grey relational coefficient results when different distinguishing coefficients are adopted.

In Figure 2, the differences between $\gamma\ (x_{0j}, x_{aj})$, $\gamma\ (x_{0j}, x_{bj})$, and $\gamma\ (x_{0j}, x_{cj})$ always change when different distinguishing coefficients are adopted. But no matter what the distinguishing coefficient is, the rank order of $\gamma\ (x_{0j}, x_{aj})$, $\gamma\ (x_{0j}, x_{bj})$, and $\gamma(x_{0j}, x_{cj})$ is always the same.The distinguishing coefficient can be adjusted by the decision maker exercising judgment and different distinguishing coefficients usually produce different results in GRA .

Step 6: Grey relation grade calculation

After calculating the entire grey relational coefficient $\gamma\ (x_{0j}, x_{ij})$the grey relational grade can be calculated using

$$\Gamma (X_0,X_i) = \sum_{j=1}^{n} \mathbf{w_j}\ \gamma\ (x_{0j}, x_{ij})\ ;\ i=1,2\ldots\ldots m \qquad (7)$$

In Equation (7), $\Gamma (X_0,X_i)$ is the grey relational grade between $X_i$and X_0.It represents the level of correlation between the reference sequence and the comparability sequence. $\mathbf{w_j}$ the weightof attribute *j* and usually depends on decision makers’ judgments or the structure of the proposed problem in addition $\sum_{j=1}^{n} w_j = 1$. The grey relational grade indicates the degree of similarity between the comparability sequence& reference sequence. As mentioned above, on each attribute, the reference sequence represents the best performance that could be achieved by any among the comparability sequences therefore if a comparability sequence for an alternative gets the highest grey relational grade with the reference sequence, the comparability sequence is most similar to the reference sequence and that alternative would be best choice .

Step 7: Determination of optimal factor levels

According to the principles of the Taguchi method, if the effects of the control factors on performance are additive, it is possible to predict the performance for a combination of levels of the control factors by knowing only the main effects of the control factor. For a factor *A* that has two levels, 1 and 2, for example, the main effect of factor *A* at level 1 (m_{A1}) is equal to the average grey relational grade whose factor *A* in experimental scenarios is at level 1, and the main effect of factor *A* at level 2 (m_{A2}) is equal to the average grey relational grade whose factor *A* in experimental scenarios is at level 2. The higher the main effect is, the better the factor level is. Therefore, the optimal levels for factor *A* will be the one whose main effect is the highest among all levels.

3.2.Fuzzy based taguchi method:- optimization of multiple responses cannot be as straightforward as the optimisation of a single process response. A higher S/N ratio for one process response may correspond to a lower S/N ratio for another process response. As a result, an overall evaluation of the S/N ratios is required for the optimisation of a multiresponse process. To solve this problem, fuzzy logic analysis is introduced into the Taguchi method for the optimisation of the multi-response process. Several fuzzy rules are derived in the fuzzy logic analysis based on the performance requirement of the process response. The loss function corresponding to each process response is fuzzified and then a single fuzzy reasoning grade is obtained by using the max–min fuzzy inference and centroid defuzzification methods. Hence, optimisationof complicated multiple process responses can also be converted into optimisation of a single fuzzy reasoning grade.

In the fuzzy logic analysis, the fuzzifier first uses membership functions to fuzzify the S/N ratios. The inference engine then performs a fuzzy inference using fuzzy rules in order to generate a fuzzy value. Finally, the defuzzifier converts the fuzzy value into a fuzzy reasoning grade.The fuzzy rule base consists of a group of if-then control rules with the three S/N ratios, x1, x2 and x3, and one multiresponse output y, that is:

Rule 1: if x1 is A1 and x2 is B1 and x3 is C1 then y is D1 else

Rule 2: if x1 is A2 and x2 is B2 and x3 is C2 then y is D2 else
. . . .
Rule n: if x1 is An and x2 is Bn and xn is Cn then y is Dn.

Ai, *Bi*, *Ci* and *Di* are fuzzy subsets defined by the corresponding membership functions, i.e. μ_{Ai}, μ_{Bi}, μ_{Ci}, and μ_{Di}.
Various degrees of membership of the fuzzy sets are calculated based on the values of x1, x2, x3, and y. Twenty-seven fuzzy rules are directly derived based on the fact that the larger S/N ratio is, the better is the process response. A fuzzy multi-response output is produced from these rules by taking the max–min inference operation. Suppose *x*1, *x*2, and *x*3 are the three S/N ratios, the membership function of the multi-response output *y* can be expressed as:

$$\mu_{D0}(y) = (\mu_{A1}(x1) \wedge \mu_{B1}(x2) \wedge \mu_{C1}(x3) \wedge \mu_{D1}(y)) \ldots\ldots \vee (\mu_{An}(x1) \wedge \mu_{Bn}(x2) \wedge \mu_{Cn}(x3) \wedge \mu_{Dn}(y))$$

where $\wedge$ is the minimum operation & $\vee$ is the maximum operation .

Finally, a centroid defuzzification method is adopted to transform the fuzzy multi-response output $\mu_{D0}(y)$ into a nonfuzzy value y_0, that is:

$$y_0 = \frac{\sum \mathbf{y}\boldsymbol{\mu}_{\mathbf{D0}}(\mathbf{y})}{\sum \boldsymbol{\mu}_{\mathbf{D0}}(\mathbf{y})}$$

Based on the above discussion, the larger the fuzzy reasoning grade, the better is the multiple process responses.

Chapter 4
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

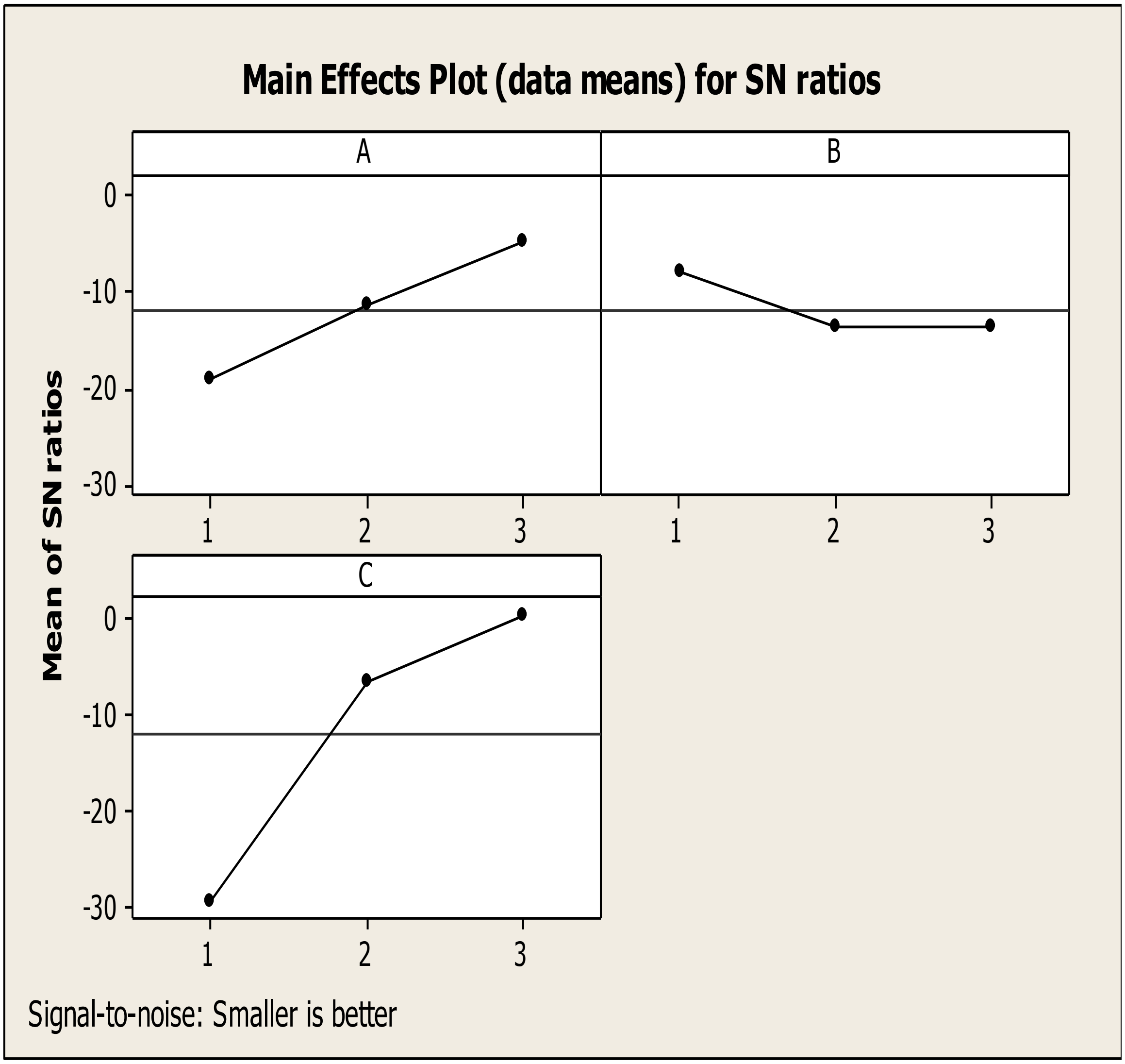
Symbol	Parameter	Unit	Level 1	Level 2	Level 3
A	Pulse on time	μs	5	100	200
B	Duty factor		0.2	0.4	0.6
C	Pulse peak current	A	1	5	7

Table 3: Experimental results

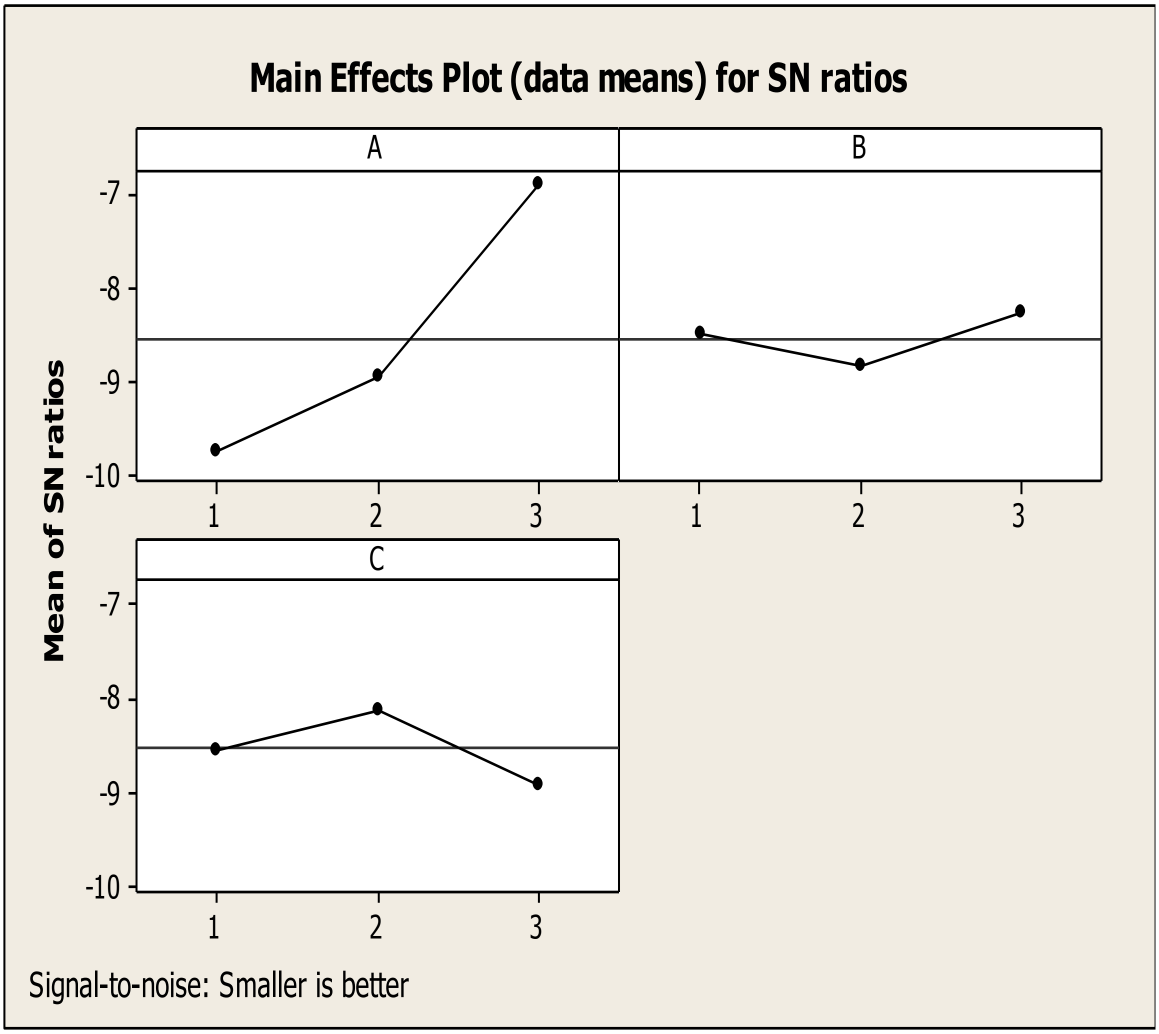
A	B	C	MRR	EWR	Ra
1	1	1	0.0024	29.896	3.01
1	2	2	0.0058	5.253	2.78
1	3	3	0.0097	4.897	3.45
2	1	2	0.0066	2.345	2.95
2	2	3	0.0087	0.765	2.98
2	3	1	0.0029	28.906	2.5
3	1	3	0.0059	0.234	2.12
3	2	1	0.0031	28.865	2.56
3	3	2	0.0037	0.789	2.01

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



Chapter 5

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 A,C 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.

Chapter 6

Conclusion

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 non linear regression model has to be developed

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