# MULTI RESPONSE OPTIMIZATION OF PROCESS PARAMETERS USING GREY RELATIONAL ANALYSIS FOR MATERIAL REMOVAL RATE AND KERF WIDTH IN WIRE ELECTRICAL DISCHARGE MACHINING PROCESS

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***Abstract :*** This paper presents an investigation on the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The experimental studies were conducted under varying pulse on time, pulse off time, open circuit voltage, and dielectric flushing pressure. The settings of machining parameters were determined by using orthogonal array. The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio The optimal search for machining parameters for the objective of minimum kerf together with maximum MRR is performed by using the established mathematical model Grey Relational Analysis (GRA).The optimum values of input parameters for Material removal rate are voltage =102volts ,pulse on time=3µs and pulse off time =3µs.The optimum values of input parameters for kerf width are voltage =93volts ,pulse on time=1µs and pulse off time =1µs. from final grey relational grade X3,Y1,Z3 is the best composition for the wire edm experiment.

***IndexTerms* – WEDM, MRR, KERF WIDTH, GRA.**

## I. INTRODUCTION

The objectives of human lives are distinguished from all other forms of life. We use tools and intelligence to create goods that serve to make life easier and more enjoyable. Through the centuries both the tools and energy sources to power these tools have evolved to meet the increasing sophistication and complexity of mankind's ideas. The last century has seen the creation of products made from the most durable and, consequently, the most un-machinable materials in history. In an effort to meet the manufacturing challenges created by these materials, tools have now been evolved to include materials such as alloy steels, carbide, diamond and ceramics. Every time new tools, tool materials, and power sources are utilized, the efficiency and capabilities of manufacturers are greatly enhanced. However as old problems are solved, new problems and challenges arise.

Scientific and engineering advances have placed unusual demands on the manufacturing industry. One of the aspects of these demands is that engineering materials such as cold rolled composites with high strength-to-weight ratios have been developed to serve specific purposes. Although they have been successfully introduced in few commercial applications, their potential of wide spread application is still impeded due to the challenges in machining these materials. They are difficult to-machine due to the presence of hard and abrasive ceramic reinforcements. The issues like rapid tool wear, surface and sub-surface damage, along with high cost are associated. Therefore, these materials have attracted researcher worldwide in last decade. As a result of this lot of work has been carried in conventional machining of these materials. In addition, nonconventional machining process like electrical discharge machining has also been employed to machine these materials. This process show promise in machining of these materials. However, relatively a very few research have been undertaken in wire electrical discharge machining (WEDM) of these materials.

Nomenclature:

1. WEDM: Wire Electrical Discharge Machining
2. MRR: Material Removal Rate
3. GRA: Grey Relational Analysis
4. S/N Ratio: Signal to Noise ratio
5. GRG: Grey Relational Grade

## II. LITERATURE REVIEW

Machining is a process in manufacturing since it decides quality of product. New methods of machining have emerged over a decade or two. One such technique is Electrical Discharge Machining (EDM). It removes materials from work piece and the process is called as spark erosion process. EDM produces heat that melts and vaporizes electrically conductive work piece material immersed in a di-electric fluid by a series of non stationary and transient electric discharges in many manufacturing industries. Scott et al (1991), this study has observed that EDM has provided one of the best only alternatives for machining material having high strength and high hardness. Due to sub-optimal parameter settings, such as poor finishing, improper gap voltage, feed rate, wire tension etc, harmful arc discharges occur which produce thermal damage on work piece and tool surfaces. Evaluation of machining performance in EDM is based on performance characteristics such as Material Removal Rate (MRR), Surface Roughness (SR), Electrode Wear Rate (EWR) and Spark Gap (SG) often called as uncontrollable factors. Kennedy et al (1995) describes the various machining parameters such as peak voltage (Vp), pulse on time (Ton), pulse off time (Toff), peak current (Ip), spark gap set voltage (Vs), wire feed rate (m/min), and wire tension (gm-in case of wire EDM). Further it is stated that they are controllable parameters. In order to optimize quality characteristics the experimentation is essential so that appropriate selection of machining parameters can be obtained. To optimize process parameters, classical arrays have been developed by Sir Ronald Fisher in England in 1920.and the classical approach is found costly and time consuming .More over hand book values also do not ensure that the selected parameters and their levels give optimal machining performance. Finney (1945), Placket and Burman (1952) and Cox and Shrivastava (1975) are some of the authors who have contributed for the development of classical experiments. The surface roughness is one of the most predominant factors in manufacturing and various investigations were carried out by several researchers for improving surface roughness of the WEDM process (Ramakrishnan et al 2004). Surface roughness in WEDM process has been found to be influenced in varying degrees by a number of factors, such as applied voltage, pulse on time, delay time, ignition current, di-electric pressure, wire tension, servo reference mean voltage and wire feed. Mustafa et al (2000) had investigated under various experimental conditions that the surface roughness is achievable for 1040, 2379 and 2738 steel materials and the relative machining parameters for WEDM process. Dan Scott et al (1991) had constructed a mathematical model to predict material removal rate and surface finish when machining of D2 tool steel material at different machining conditions. They found that no single combination of levels of the different factors can be optimal under all circumstances. To find the optimal machining parameters the non-dominated 14 point approach is applied, using explicit enumeration of all possible combinations and dynamic programming method. Tarng et al (1995) had 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 when machining of SUS-304 stainless steel materials. Speeding et al (1997) had attempted to model the WEDM process through the response surface methodology and artificial neural networks, values, waviness and speed of the artificial neural networks using a constrained optimization model.Likewise, researchers had attempted to optimize the surface finish. In this context it is essential to know some of the concepts of optimization. Rao (1990) defines optimization; “Extracting the best thing from the available choices”. Optimization means the most economical one. In general, optimization means minimizing. But it is depending upon our objective of its function where optimization may be maximization also:. If objective function is profit (or) accuracy, the optimization is maximization . If objective is time, cost etc, then optimization is minimization. Technically the word optimize is stronger than the words improvement enhancement In the optimum machining process, three main steps are to be undertaken in the beginning, i.e. collection of the data to describe the process, actual processing and analyze the process as in conventional machining process. Then the constraints that are used in optimization are ensured for process control. 19 The decision making step is the next step which checks for the design. Change in the method of experimentation is warranted only when the design is not satisfied. One of the software, viz QUALITEK-4, could be employed for process optimization in machining.

Formulation of optimum problem involves variable description of the problem into a well designed mathematical statement. The formation process begins by identifying a set of variables to describe the system called process variables which are pulse on-time, pulse off-time, peak current, gap voltage and fluid pressure in EDM.

For optimization of process parameter to obtain a good surface finish on the component is applicable not only for EDM, and WEDM, but also for machining the component in turning, milling, grinding, drilling etc.

### 2.1 WORKPIECE MATERIAL

Work piece is a stripped piece of a large metal sheet which has been cold rolled and gone through a tempering process to remove the residual stress and the change in chemical composition is noticeable. The chemical composition of the workpiece material is given in the table 1:

Table 1: Chemical composition of Work piece

| CHEMICALS | % |
|---|---|
| Fe | 98.396 |
| C | 0.477 |
| Si | 0.223 |
| Mn | 0.637 |
| P | 0.016 |
| S | 0.005 |
| Cr | 0.186 |
| Mo | <0.001 |
| Ni | 0.001 |
| Al | 0.034 |
| Cu | 0.005 |
| Ti | 0.006 |
| V | 0.002 |
| W | <0.008 |
| Ca | >0.008 |
| N | <0.005 |

Figure 1: Workpiece before machining

## III. RESPONSE PARAMETERS

### 3.1 MATERIAL REMOVAL RATE(MRR)

The mechanism of metal removal in wire electrical discharge machining mainly involves the removal of material due to melting and vaporization caused by the electric spark discharge generated by a pulsating direct current power supply between the electrodes.

### 3.2 KERF WIDTH

The width of a saw cut, which depends on several factors: the width of the saw blade; the set of the blade's teeth; the amount of wobble created during cutting; and the amount of material pulled out of the sides of the cut. Although the term "kerf" is often used informally, to refer simply to the thickness of the saw blade, or to the width of the set, this can be misleading, because blades with the same thickness and set may create different kerfs. For example, a too-thin blade can cause excessive wobble, creating a wider-than-expected kerf. The kerf created by a given blade can be changed by adjusting the set of its teeth with a tool called a saw tooth setter.

Figure 2: Wire EDM machine on which the work piece was machined

### 3.3 EXPERIMENTAL DETAILS OF MRR AND KERF

Table 2. Input Parameters and Levels

| FACTOR | PARAMETER | LEVEL-1 | LEVEL-2 | LEVEL-3 | Units |
|---|---|---|---|---|---|
| X | VOLTAGE (X) | 82 | 93 | 102 | Volts |
| Y | T-ON (Y) | 3 | 2 | 1 | µs |
| Z | T-OFF (Z) | 1 | 2 | 3 | µs |

Table 3. Experimental Results of material removal rate and kerf

| Exp. No | VOLTAGE | T-ON | T-OFF | MRR | KERF |
|---|---|---|---|---|---|
| 1 | 82 | 3 | 1 | 0.053 | 0.3 |
| 2 | 82 | 2 | 2 | 0.053 | 0.3 |
| 3 | 82 | 1 | 3 | 0.052 | 0.305 |
| 4 | 93 | 3 | 2 | 0.0531 | 0.285 |
| 5 | 93 | 2 | 3 | 0.0535 | 0.281 |
| 6 | 93 | 1 | 1 | 0.0491 | 0.3 |
| 7 | 102 | 3 | 3 | 0.0606 | 0.298 |
| 8 | 102 | 2 | 1 | 0.05 | 0.291 |
| 9 | 102 | 1 | 2 | 0.0497 | 0.302 |

## IV. METHODOLOGY ADOPTED

### 4.1 GREY RELATIONAL ANALYSIS

The information is enough to evaluate even the complex project performance with the help of Grey relational analysis. Optimum condition of various input parameters are determined by deploying Grey Relational Analysis (GRA) to obtain the best quality characteristics the following formulae used to analyze the GRA. Signal to noise ratio for material removal rate is taken as larger is better. The formula for larger is better is shown in equation (1)

$$\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{{y_{ij}}^{2}}\right)\right) \qquad (1)$$

Signal to noise ratio for kerf width is taken as Smaller is better. The formula for smaller is better is shown in equation (2)

$$\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\left({y_{ij}}^{2}\right)\right) \qquad (2)$$

$$N - S/N\ ratio = \eta_n = \frac{\eta_i - \min(\eta_i)}{\max(\eta_i) - \min(\eta_i)} \quad (3)$$

In the grey relations, the quality loss function $(\Delta)$ calculated by using the N-S/N ratio.

$$Quality\,Loss = \Delta = \max(\eta_{n_i}) - \eta_{n_i} \quad (4)$$

**Computed the grey relational coefficient (GRC) form the quality loss function $(\Delta)$.**

$$GRC = \frac{\min(\Delta_i) + \xi * \max(\Delta_i)}{\Delta_i + \xi * \max(\Delta_i)} \quad (5)$$

Where $\xi$ = Distinguishing coefficient, whichdefined in the range $0 \le \xi \le 1$ (the value of $\xi$ can be adjusted on the practical needs ofthe system).

The N-S/N ratio $(\eta_n)$, quality loss function $(\Delta)$ and grey relational co-efficient (GRC)of Experiment results (MRR and KERF WIDTH) calculated and shown in Table 5, Table 6 respectively.

Table5(a). Larger is better-Material Removal Rate

| Exp No | X | Y | Z | MRR-1 | MRR-2 | MRR-3 |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0.053 | 0.054 | 0.052 |
| 2 | 1 | 2 | 2 | 0.053 | 0.052 | 0.054 |
| 3 | 1 | 3 | 3 | 0.052 | 0.051 | 0.053 |
| 4 | 2 | 1 | 2 | 0.0531 | 0.053 | 0.0532 |
| 5 | 2 | 2 | 3 | 0.0535 | 0.0534 | 0.0536 |
| 6 | 2 | 3 | 1 | 0.0491 | 0.05 | 0.049 |
| 7 | 3 | 1 | 3 | 0.0606 | 0.05992 | 0.059 |
| 8 | 3 | 2 | 1 | 0.05 | 0.0501 | 0.05 |
| 9 | 3 | 3 | 2 | 0.049 | 0.0489 | 0.052 |

Table5(b) Larger is better-Material Removal Rate contd.,

| Exp No | Loss Factor | SNRA | N-SNRA | DELTA | GRC-MRR |
|---|---|---|---|---|---|
| 1 | 356.2521964445 | -25.5175755 | 0.368010763 | 0.631989237 | 0.441700313 |
| 2 | 356.2521964445 | -25.5175755 | 0.368010763 | 0.631989237 | 0.441700313 |
| 3 | 370.0961912360 | -25.6831462 | 0.268905797 | 0.731094203 | 0.406142762 |
| 4 | 354.6614933347 | -25.4981404 | 0.379643967 | 0.620356033 | 0.446286703 |
| 5 | 349.3779325882 | -25.4329547 | 0.418661899 | 0.581338101 | 0.46239007 |
| 6 | 410.4304912159 | -26.1323962 | 0 | 1 | 0.333333333 |
| 7 | 279.3660775705 | -24.4617367 | 1 | 0 | 1 |
| 8 | 399.4682624106 | -26.0148228 | 0.070375424 | 0.929624576 | 0.349742169 |
| 9 | 401.5046436923 | -26.0369057 | 0.057157338 | 0.942842662 | 0.346538131 |

Table6.(a) Smaller is better-kerf width contd.,

| Exp No | X | Y | KERF-1 | KERF-2 | KERF-3 |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 0.3 | 0.29 | 0.31 |
| 2 | 1 | 2 | 0.3123 | 0.291 | 0.3124 |
| 3 | 2 | 1 | 0.319 | 0.2895 | 0.30826 |
| 4 | 2 | 2 | 0.285 | 0.2851 | 0.2849 |
| 5 | 3 | 1 | 0.285 | 0.2854 | 0.2715 |
| 6 | 3 | 2 | 0.3 | 0.321 | 0.312 |
| 7 | 4 | 1 | 0.298 | 0.29978 | 0.29758 |
| 8 | 4 | 2 | 0.291 | 0.2812 | 0.3024 |
| 9 | 5 | 1 | 0.301 | 0.2951 | 0.311 |

Table6.(b) Smaller is better-kerf width contd.,

| Exp No | Loss Factor | SNRA | N-SNRA | DELTA | GRC-KERF |
|---|---|---|---|---|---|
| 1 | 0.0900666667 | 10.4543591 | 0.350205054 | 0.649794946 | 0.4348601478 |
| 2 | 0.0932686833 | 10.30264154 | 0.180392859 | 0.819607141 | 0.3789006475 |
| 3 | 0.0935318259 | 10.29040588 | 0.166697904 | 0.833302096 | 0.3750087858 |
| 4 | 0.0812250067 | 10.90310244 | 0.852467893 | 0.147532107 | 0.7721624841 |
| 5 | 0.0787968033 | 11.03491401 | 1 | 0 | 1.0000000000 |
| 6 | 0.0967950000 | 10.14147076 | 0 | 1 | 0.333333333 |
| 7 | 0.0890753016 | 10.50242698 | 0.404005768 | 0.595994232 | 0.4562067806 |
| 8 | 0.0850667333 | 10.70240244 | 0.627831353 | 0.372168647 | 0.5732836212 |
| 9 | 0.0914686700 | 10.38727636 | 0.27512167 | 0.72487833 | 0.4082038091 |

Table 7 Grey relational grade of each experiment

| Exp No | GRC-MRR | GRC-KERF | GRG | RANK |
|---|---|---|---|---|
| 1 | 0.442272832 | 0.58809342 | 0.51518313 | 5 |
| 2 | 0.442272832 | 0.73486956 | 0.5885712 | 3 |
| 3 | 0.406671341 | 0.74996486 | 0.5783181 | 4 |
| 4 | 0.445895927 | 0.36969454 | 0.40779524 | 7 |
| 5 | 0.461963894 | 0.33333333 | 0.39764861 | 8 |
| 6 | 0.333333333 | 1 | 0.66666667 | 2 |
| 7 | 1 | 0.55309382 | 0.77654691 | 1 |
| 8 | 0.349528089 | 0.44332869 | 0.39642839 | 9 |
| 9 | 0.348364207 | 0.64506002 | 0.49671211 | 6 |

## V. RESULTS AND DISCUSSION

The above study was solely dedicated to understand the effects caused by various machining parameters like voltage, pulse on time and pulse off time and their contribution to the variation of metal removal rate (MRR) and Kerf width. Thus, the conclusions of the above research are as follows:

Input energy is a function of pulse duration and voltage. As the Signal-to-Noise ratio for MRR when larger is better shows the optimum conditions for it as : Voltage: 93 volts , Ton: 3µs , Toff: 3 µs It can be concluded that signal to noise ratio varies for different parameters. As the Signal-to-Noise ratio for Kerf width when smaller is better shows the optimum conditions for it as: Voltage: 93 volts , T on: 2µs , T off: 3 µs It can be concluded that signal to noise ratio varies for different parameters, for producing optimal working condition. From this Grey Relational analysis, it is revealed that material removal rate and kerf width is influenced by pulse on time followed by voltage and pulse off time. The optimum values of input parameters for Material removal rate are voltage =102volts ,pulse on time=3µs and pulse off time =3µs.The optimum values of input parameters for kerf width are voltage =93volts ,pulse on time=1µs and pulse off time =1µs. from final grey relational grade X3,Y1,Z3 is the best composition for the wire edm experiment.

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