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Optimization of Process Parameters of Wire EDM Process for Machining of Monel R-400 Material

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Abstract: One of the most important nontraditional machining processes is wire electrical discharge machining which is used for machining of conductive materials with high precision. Monel R- 400 material is selected for finding the optimal machining parameters on Wire-EDM, Monel R-400 materials are widely used in marine applications, oil production and refining industries. The input process parameters taken into consideration are the pulse on time (Ton), pulse off time (Toff), peak current (I), and wire feed (WF) and the data is collected through experimentation. The output response such as material removal rate (MRR) has been considered for analysis. Taguchi L27 design is used to conduct the experiments, and response surface methodology is applied for the development of the MRR model and optimization of response.
Keywords: WEDM, RSM, MRR, Monel R-400.

I. INTRODUCTION AND LITERATURE SURVEY

The wire electric discharge machining (WEDM) process contributes a predominant role in some manufacturing sectors recently; since this process has the capacity to cut complex shapes of components in all electrical conductive materials with better accuracy. It is a thermal mass-reducing process, In WEDM process there is no virtual contact between the tool and Job, therefore the Job hardness is not a factor for machining materials by this process. In WEDM, material removal happens from any electrically conductive material by the commencement of quick sparkle releases between the hole of the work and instrument cathode associated in an electrical circuit, and the fluid dielectric medium is ceaselessly provided to convey the dissolved particles and to give the cooling impact. A little breadth wire running from 0.05 to 0.3 mm is applied as the device cathode. The wire is consistently provided from the gracefully spool through the work-piece, which is clasped on the table by the wire foothold rollers. A hole of 0.025–0.05 mm is kept up continually between the wire and workpiece, De-ionized water is applied as the dielectric. An assortment tank that is situated at the base is utilized to gather the pre-owned wire and afterward dispose of it. The wires once utilized can't be reused again because of the variety in dimensional exactness. The dielectric is consistently flashed through the hole along the wire, to the starting zone to expel the items shaped during the disintegration. Wire-slice EDM is normally used to cut plates as thick as 300 mm and to make punches, devices, and dies from hard metals that are hard to machine with different strategies. The wire, which is continually taken care of from a spool, is held among upper and lower diamond guides. The guides, ordinarily CNC controlled. The wire-cut procedure utilizes water as its dielectric liquid, controlling its resistivity and other electrical properties with channels and de-ionizer units.

The water flushes the remove trash from the cutting zone. Flushing is a significant factor in deciding the greatest feed rate for a given material thickness. Alongside more tight resistances, multi hub EDM wire-cutting machining focuses have included highlights, for example, multi sets out toward cutting two sections simultaneously, controls for forestalling wire breakage, programmed self-stringing highlights if there should be an occurrence of wire breakage, and programmable machining techniques to streamline the activity. Wire-cutting EDM is usually used when low residual stresses are anticipated because it does not need high cutting forces for elimination of material. If energy per pulse is moderately low, little change in the mechanical properties of a material is required because of these low residual stresses, albeit material that hasn't been stress-relieved can twist in the machining procedure. The workpiece may experience a critical thermal cycle, such thermal cycles may cause development of a recast layer on the part and stress on the work piece. If machining happens after warmth treatment, dimensional exactness won't be influenced by heat-treat distortion.

A large number of publications are available in the literature of WEDM on various types on materials, aiming to optimize the input parameters for desired response these are as follows:

1) *Hascalyk et al. [1]* audited an exploratory examination of the machining qualities of AISI D5 apparatus steel in wire electrical machining process. During test, boundaries, for example, open circuit voltage, pulse length, wire speed and dielectric liquid pressure were changed to investigate their impact on a superficial level harshness and metallurgical structure. Optical and examining electron microscopy, surface harshness and small-scale hardness tests were utilized to contemplate the attributes of the machined job. They found that the intensity of the process energy vitality influences the measure of recast and surface unpleasantness just as small-scale breaking, the wire speed and dielectric liquid pressure not appearing to have quite a bit of an impact.
2) *Mahapatra et al. [2]* improved wire electrical machining process boundaries utilizing Taguchi strategy. They accept Taguchi's boundary as pulse duration, discharge current, pulse frequency, wire tension, wire speed, and dielectric flow. They upgrade metal evacuation rate, surface completion and cutting width all the simultaneously.
3) *Sharma et al. [3]* investigated the effect of parameters on cutting speed and dimensional deviation for WEDM using HSLA as work piece. The High strength low-alloy steel (HSLA) is a hard alloy with high hardness and wear-resisting property. They saw that the most prominent factor for cutting speed and dimensional deviation is pulse-on time, while two-factor interactions play an important role in this analysis. Response surface methodology was used to optimize the process parameter for cutting speed and dimensional deviation. The central composite rotatable design was used to conduct the experiments.
4) *Kuriakose et al. [4]* analyzed the optimization of WEDM process using NSGA algorithm and a multiple regression model is used to represent relationship between input and output variables, they taken cutting velocity and surface finish as output parameters.
5) *Kumar et al. [5]* optimized WEDM process parameters of Incoloy800 super alloy with multiple performance characteristics such as Material Removal Rate (MRR), surface roughness and Kerf based on the Grey–Taguchi Method, the relatively significant parameters were determined by Analysis of Variance
6) *Khan et al. [6]* investigated the effect of the WEDM process parameters on the surface roughness and the kerf width of stainless steel (SS304), Surface roughness and kerf width are selected as quality targets. An optimal parameter combination of the WEDM process is obtained using gray relational analysis. Result showed that the pulse on time is found to be the most influential factor for both the surface roughness and kerf width.
7) *Mahapatra et al. [7]* used genetic algorithm for optimization of WEDM parameters, they optimized MRR and SF. As genetic algorithm is single optimization techniques so they convert MRR and SF as a single optimization function by giving different weights, then they optimized WEDM parameters.

II. EXPERIMENTAL SETUP AND DATA COLLECTION

The Monel R-400 sample of dimensions(300mmX10mmX10mm) is taken for the study. Monel R-400 is a nickel-copper composite that is impervious to the ocean water and steam at high temperatures. Input parameters are selected as Pulse on time (Ton) in microseconds, pulse off time (Toff) in microseconds, Current (I) in ampere, wire feed (W.F) in m/min. Whereas output responses to be measured as material removal rate in mm^3/min. Other constant input parameters taken as Wire Type - Plane Brass wire, Wire Diameter - 0.25 mm, Water pressure - 12 kg/cm2, Dielectric used - Deionized water. While machining workpiece in WEDM, the cut length is taken across the width of the sample. But to measure the kerf width, initially the cut is restricted up-to 7mm. The experimental design of matrix has been created on the basis Fractional Factorial design having 3^ ((4-1)) =27 of data i.e. L_{27} form. The material removal rate is calculated in mm3/min by using given formula

MRR = Volume of material removal / Time = (Length of cut * kerf *thickness of cut)/ time take to cut

Table 1. The input process parameters and their levels in WEDM

Factors	Symbols	Low level	Medium level	High level
Pulse on time	Ton	100	105	110
Pulse off time	Toff	45	50	55
Current	I	120	130	140
Wire Feed	W.F	5	6	7

Table 2. Design matrix and output responses

S.No.	Ton	Toff	I	W.F	Kerf(mm)	MRR (mm^3/min)
1	100	45	120	5	0.3453	2.6222
2	100	45	120	5	0.3314	2.6689
3	100	45	120	5	0.3263	2.4099
4	100	50	130	6	0.3461	1.9428
5	100	50	130	6	0.3344	1.9359
6	100	50	130	6	0.3273	1.8613
7	100	55	140	7	0.3398	1.5676
8	100	55	140	7	0.3385	1.5575
9	100	55	140	7	0.3376	1.5470
10	105	45	130	7	0.3318	2.7268
11	105	45	130	7	0.3322	2.7603
12	105	45	130	7	0.3298	2.7126
13	105	50	140	5	0.3460	3.2784
14	105	50	140	5	0.3425	3.2364
15	105	50	140	5	0.3322	3.1491
16	105	55	120	6	0.3339	2.3954
17	105	55	120	6	0.3354	2.3610
18	105	55	120	6	0.3422	2.3830
19	110	45	140	6	0.3390	5.1413
20	110	45	140	6	0.3549	5.2760
21	110	45	140	6	0.3584	4.8596
22	110	50	120	7	0.3480	3.2597
23	110	50	120	7	0.3456	3.2194
24	110	50	120	7	0.3316	3.1078
25	110	55	130	5	0.3293	4.0132
26	110	55	130	5	0.3432	3.9985
27	110	55	130	5	0.3414	3.9309

III. RESULT AND DISCUSSION

A. Development of Model

The regression models for material removal rate have been developed by the response surface methodology. A quadratic model has been used to obtain the regression models for two response separately. These models have been developed in MiniTab-17. The models have been developed as given below.

Maximize MRR =142.7-2.072*Ton-1.176*Toff-0.2958*I+2.611*W.F+0.01085*Ton*Ton+0.1093*Toff*Toff+0.001248*I*I-0.2493*W.F*W.F

Subjected to: $100 \leq Ton \leq 110$, $45 \leq Toff \leq 55$, $120 \leq I \leq 140$, $5 \leq WF \leq 7$

B. Analysis for MRR

It is seen from the Fig. 1. that the MRR increases with the increase of pulse on time, and peak current and decreases with increase in pulse off time. This is due to the discharge energy increases with the pulse on time and peak current, so the more material removes through the workpiece. As the pulse off time decreases, the number of discharges increases so material removal rate decreasing on increasing off Time. From the Fig.8. we can also see if we increase wire feed rate than firstly MRR increase and after a certain limit MRR will be decrease

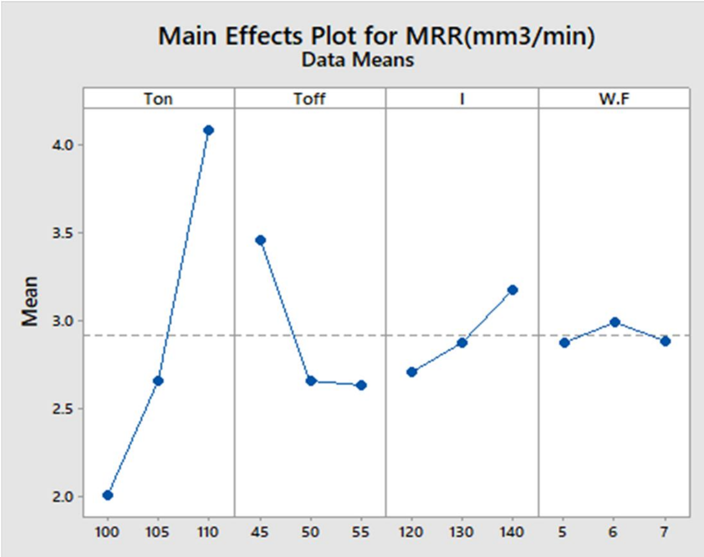

Fig. 1. Effect of process parameters on MRR

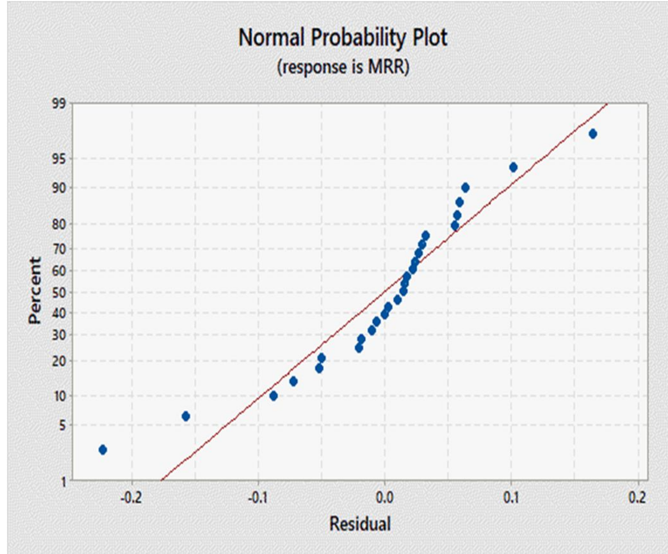

Fig. 2. Normal probability plot for MRR

Fig. 2. Shows that the residuals are normally distributed, it means that the regression model is perfectly fitted. If residuals are not normally distributed then we are missing something in the model means the regression model is not perfectly fitted or there is some mistake in the model.

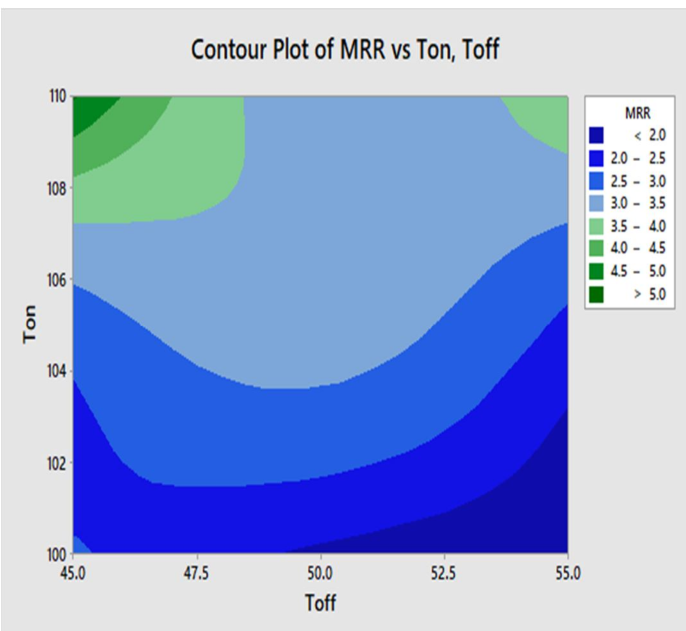

Fig. 3. Contour plot of MRR vs Ton, Toff

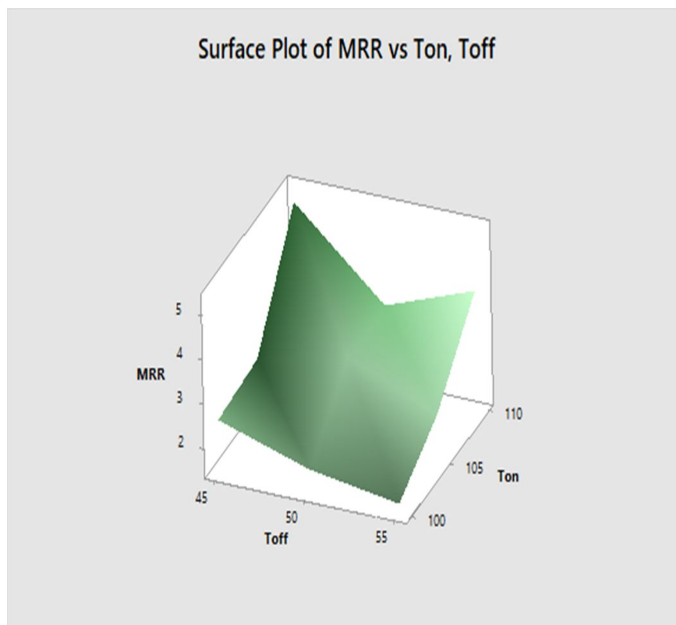

Fig. 4. Surface plot of MRR vs Ton, Toff

Fig. 3 shows the contour plot of material removal rate vs on time, off time the dark blue region shows that the lowest material removal rate and dark green region shows the highest MRR. The Fig. 4. shows when the on time is nearly 110µs and off time is 45µs then the MRR is high means greater than the 5 mm^3/min.

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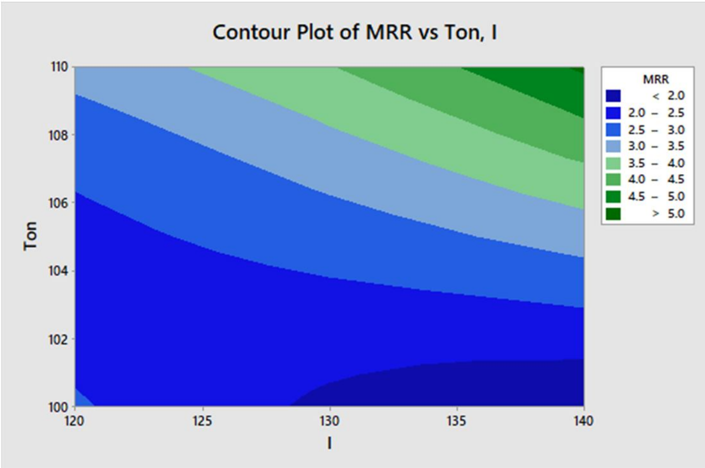

Fig. 5. Contour plot of MRR vs Ton, I

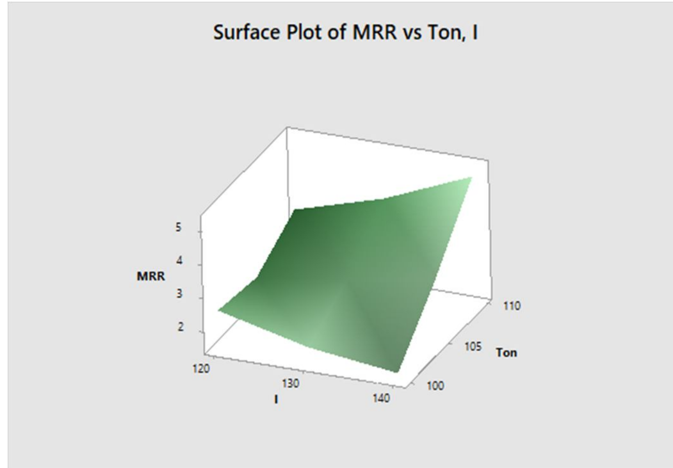

Fig. 6. Surface plot of MRR vs Ton, I

Fig. 5. shows the contour plot of material removal rate vs on time, peak current the dark blue region shows that the lowest material removal rate and dark green region shows the highest MRR. The Fig. 6. shows when the on time is nearly 110µs and peak current 140 amp then the MRR is high, greater than the 5 mm^3/min. Fig. 6. shows when we increase Ton and I then MRR increases.

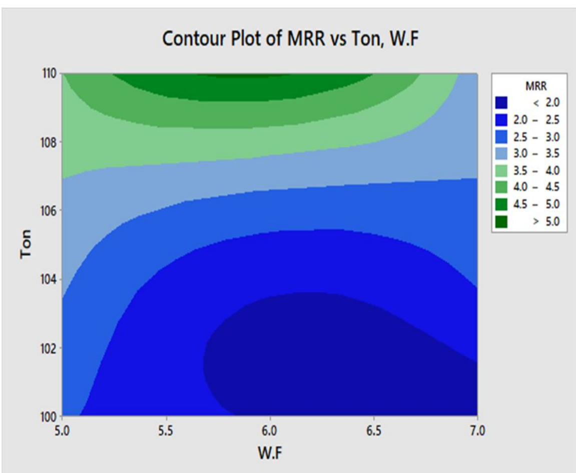

Fig. 7. Contour plot of MRR vs Ton, W.F

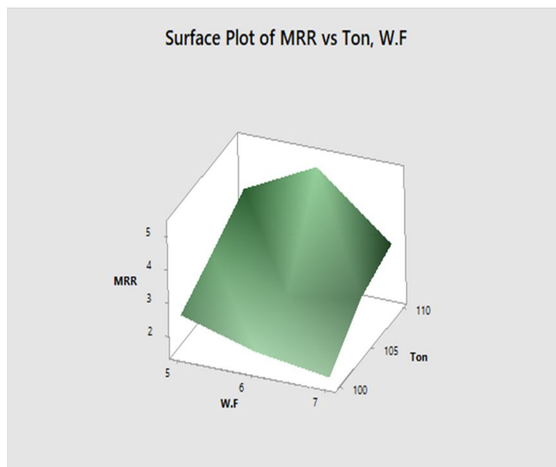

Fig. 8. Surface plot of MRR vs Ton, W.F

Fig. 7. shows the contour plot of material removal rate vs on time, wire feed and Fig. 8. shows when the on time is nearly 110µs and wire feed is 6 m/min then the MRR is high.

C. Optimization Using Desirability Approach

Desirability analysis is the most enticing approach for optimizing input parameters to meet the objectives. This technique makes use of an objective function D(X) called the desirability function, also called utility transfer function, this translates evaluated response into a scale-free value (di) called desirability. The desirability value varies from 0 to 1. 1 shows the absolute case and zero shows the responses that are exterior permissible boundaries.

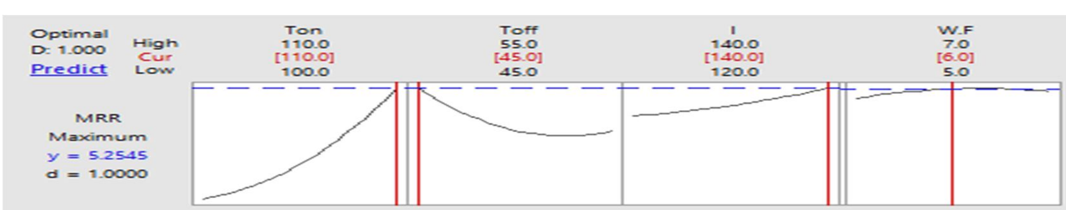

Fig. 9. Optimization plot for MRR

The above graph shows optimization plot for MRR. The ultimate objective of our work was to maximize the MRR. Desirability approach was used for finding out the optimal values of the variables in order to get the maximum value of MRR. From the Fig. 9. it is clear that highest value 5.2545 mm^3/min is obtained from the following combination of the variables:

Ton = 110 µs

Toff = 45 µs

I = 140 A

W.F = 6 m/min

The above results are obtained with the composite desirability of 1.

IV. CONCLUSIONS

In the work, experiments are carried out for material removal rate with different input process parameters. The different input process parameters are pulse on time, pulse off time, peak current and wire feed rate. There are 27 experimental readings taken for all variables to conduct the parametric study. Finally, it can be concluded that: Material removal rate increases with the increase of pulse on time, peak current and decreases with the increase of pulse off time, and wire feed. Here the discharge energy increases with the pulse on time and peak current. So, the more material removes through the workpiece. As the pulse off time decreases, the number of discharges increases so material removal rate decreasing on increasing off Time. Desirability approach was been used for finding out the optimum values of the variables in order to get the maximum value of MRR. From the graph it is clear that highest value 5.2545 is obtained for the following combination of the variables: Ton = 110 µs, Toff = 45 µs, I = 140 A, W.F = 6 m/min. These results are obtained with the composite desirability of 1.

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