Investigation and Optimization of Materiel Removal Rate For Wire Cut Electro Discharge Machining In EN5 Steel Using Response Surface Methodology.

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Abstract- EN5 is medium strength mild steel so it is widely used in various machineries parts like shafts, racks, pinions, studs, bolts, nuts, rollers etc. Wire Electric Discharge Machine (WEDM) seems a good option for machining the complicated shapes on medium strength steel. this paper, identify the effects of various process parameters of WEDM such as pulse on (Ton) ,pulse off (Toff), peak current (Ip), servo voltage (Sv) for analysis the material removal rate (MRR) while machining EN5 mild steel material. Central Composite Design is used to plan and design of experts. The output response variable being material removal rate will be measured for all the number of experiments conducted. As the lowest value of MRR indicates the poor cutting rate, the optimum parameter level combination would be analyzed which gives desired material removal rate. These optimized values of various parameters would then be used in performing machining operation in order to obtain desirable outputs.

Keywords – En5 Steel, Wire Edm, Process Parameters, Rsm Technique, Material Removal Rate.

I.INTRODUCTION

The main objective of this paper is to study different parameters likes (Ton,Toff,Ip,Sv) of WEDM operations using response surface methodology, in particular central composite design (CCD), to develop empirical relationships between different process parameters and output responses namely MRR. The mathematical models so developed are analysed and optimised to yield values of process parameters producing optimal values of output responses. **In 1984 Pandey and Jilani** [1] worked on the machining characteristics of distilled water, tap water and a mixture of 25% tap and 75% distilled water when used as dielectric fluid in EDM are reported. Two different tool materials, brass and copper with positive and negative polarities have been used to machine low carbon steel work-pieces at low current densities. All the experiments have been planned statistically and response surface equations for metal removal rate, relative electrode wear and surface roughness have been obtained. The best machining rates have been achieved with the tap water and a special feature of machining in water was the possibility of achieving zero electrode wear especially when copper tools with negative polarities were used. **In 1997 Spedding and Wang [2]** developed responsive surface methodology (RSM) and artificial neural network (ANN) models for the WEDM process**. In 2005 Kansal [3]** optimised the process parameters of powder mixed electrical discharge machining by using response surface methodology. Authors found out the most important parameters maximising the mrr and minimising surface roughness. **In 2007 Mahapatra and Patnaik [4]** optimized the wire electrical discharge machining parameters**. In 2011 Hari S, Rajesh K [5]** worked on cryogenic treated D-3 as a workpiece and brass wire as a tool. Charmills Technologies Robofill 290 was the machine tool used for research work. The planning of experiments was carried by Taguchi technique and L 27 orthogonal array was selected. The results show that cutting rate decreases with increase in pulse width, time between two pulses, and servo reference mean voltage. Cutting rate first decreases and then increases with the increase in mechanical tension. **In 2012 Jangra KAMAL [6]** presented a study on unmachined surface area named as surface projection in the die cutting after rough cut in WEDM. Using scanning electron microscope images, length of unmachined surface projections have been determined. Tungsten-carbide was used as a work-piece and brass wire as electrode. **Gupta et al. [7]** optimized the process parameters of WEDM considering kerf width as a response variable. Central composite design was selected for the planning of experiments. Kerf width increases with the increase in pulse on-time and decrease in pulse off-time due to higher discharge energy. **In 2013 Sharma et al. [8]** optimized the process parameters for the cutting speed and dimensional deviation for high strength low alloy steel (HSLA) on WEDM. Response surface methodology was used for the modeling and multi-response optimization.

In the present study EN5 steel is chosen for parametric investigation and optimization of material removal rate by using response surface methodology and Wedm.

The rest of the paper is orgainsed as follows. proposed experimental methodology is explain in section II.Experimental results are presented in section III .Concluding remarks are given in section IV

II. EXPERIMENTAL METHODOLOGY

A. Machine Tool And Workpiece –

In this research work, MRR is response characteristics. These response characteristics are investigated under the varying conditions of input process parameters, which are Ton, Toff, servo gap voltage (SV), peak current (IP). The experiments were performed on Electronica make ELEKTRA Sprintcut 734 CNC Wire cut machine. ELEKTRA Sprintcut 734 provides full freedom to the operator in choosing parameter values with in a wide range. A brass wire of 0.25 mm diameter is used as the tool material. Deionized water is used as the dielectric, which flush away the metal particle from the workpiece. The workpiece shape is rectangular of 5×5×5 mm of EN5. The profile of the work piece to be cut is illustrated in Figure 1.and Table 1 gives the chemical composition

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Figure 1. Profile Of workpiece During Machining

Table -1 Composition of EN-5

Carbon %	Manganese %	Phosphorus %	Sulphur %	Silicon %	Copper %	Nickel %	Chromium %	Vanadium %	Moly %	Iron
0.211	1.569	0.009	0.021	0.579	0.048	0.485	0.521	0.347	0.593	Remaining

B. Examining The Output Response-

The MRR (mm^3/min) is calculated from the cutting speed (directly displayed by the machine tool)*length of work piece removed *breadth of work piece removed [9].

i.e MRR = cutting speed* length * breadth of work piece removed .

Values of the MRR are noted at a distance of 5 mm, 5 mm, and 5 mm from the initiation of cut along a particularaxis. This is done to ensure that readings are to be noted only when the cutting process is properly stabilised. The offset of the wire is set at zero.

C. Response surface methodology and design of experiment -

RSM is a compilation of mathematical and statistical techniques useful for the modeling and analysis of problems in which output factors are influenced by several input parameters and the main aim is to optimize this output parameters [10]. Graphical representation of the procedure for RSM is as follows:

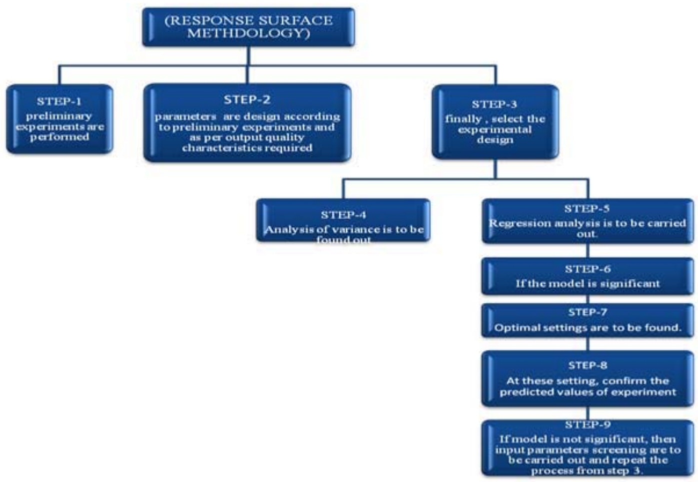

Figure 2. Graphical representation of procedure for RSM

Table 2 : Different levels of Process parameters with coded form and units

Sr. no.	Parameters	Coded form	Min. value	Max. Value	-alpha	+alpha
1	Ton (μs)	A	105	125	98.1821	131.818
2	Toff (μs)	B	20	60	6.36414	73.6359
3	Ip (A)	C	50	180	5.68347	224.317
4	Sv (V)	D	30	80	12.9552	97.0448

Table 3 : WEDM machining conditions

Work piece	:	EN5 Mild Steel
Electrode(tool)	:	0.25mm Ø, Brass wire
Work piece height	:	9mm
Cutting length	:	70 mm
Dielectric Conductivity	:	20mho
Dielectric temperature	:	20-24^{0}C

Table 4 : (Design of experiments and results for wire EDM output response)

		PROCESS PARAMETERS				RESPONSE VARIABLE
STD.	RUN ORDER	TON (μs)	TOFF (μs)	IP (A)	SV (V)	MRR (mm^3/min)
17	1	115	40	115	55	61.325
7	2	105	60	180	80	3.891
5	3	125	20	50	80	35.328

13	4	115	40	5.683466	55	5.865
2	5	125	60	50	30	14.131
6	6	105	20	180	30	22.56
20	7	115	40	115	55	58.631
15	8	115	40	115	12.95518	50.784
11	9	115	6.364143	115	55	33.12
14	10	115	40	224.3165	55	56.16
3	11	125	20	180	80	81.696
19	12	115	40	115	55	58.406
12	13	115	73.63586	115	55	26.496
21	14	115	40	115	55	49.632
8	15	105	20	50	30	8.798
10	16	131.8179	40	115	55	102.211
9	17	98.18207	40	115	55	11.28
4	18	105	60	50	80	2.246
1	19	125	60	180	30	64.588
18	20	115	40	115	55	58.375
16	21	115	40	115	97.04482	8.832

III.RESULT AND DISCUSSION

There are 21 experiments in total carried out according to the design of experiments. The average values of mrr (mm^3/min) are shown in Table 4. For analysis of data, checking the goodness of fit of model is required. The model adequacy checking includes test for significance of regression model, test for significance on model coefficients, and lack of fit test .For this purpose, ANOVA is performed.

A. Analysis Of Material Removal Rate-

According to the fit summary obtained from analysis, it is found that quadratic model is statistically significant for MRR. The results of the quadratic model for MRR in the form of ANOVA are presented in Table 5. If the F value is more corresponding, p value must be less corresponding resulting in a more significant corresponding coefficient. Non significant terms are removed by backward elimination for the fitting of MRR in the model. Alpha out value is taken at 0.05 (i.e., 95 % confidence level). When quadratic model with backward elimination is selected, the model is not hierarchical so the Toff (B in coded form) is hierarchically added. A model is said to be hierarchical if the presence of higher-order terms (such as interaction and second-order terms) requires the inclusion of all lower-order terms contained within those of higher order. It is found from Table 5 that F value of the model is 104.61 and related p value is <0.0001, results of a significant model. The lack of fit is a measure of the failure of the model to represent data in the experimental domain at which points are not included in the regression variations in the model that cannot be accounted for by random error. If there is a significant lack of fit, as indicated by a low probability value, the response predictor is discarded . The lack of fit is non significant and its value is 0.7937. From Table 5, it is found that R^2 of the model is 0.9922, which is very close to 1. The meaning behind this is that 99.22 % variation can be explained by this model and only 0.35 % of total variation cannot be explained, which is an indication of good accuracy. The predicted R^2 is in logical concurrence with the adjusted R2 of 0.9928. Figure (3) shows the normal probability plot of residuals for MRR. Most of the residuals are found around the straight line, which means that errors are normally distributed. Adequate precision compares the significant factors to the non significant factors, i.e., signal to noise ratio. According to the results obtained from the software, ratio greater than 4 is desirable. In this, the adequate precision is 37.005, so the signal to noise ratio is significant. By applying multiple regression analysis on the experimental data, the empirical relation in terms of coded factors is obtained as follows:

MRR =+57.11+27.03* A-1.97 * B+14.41* C-12.47 * D-14.11 * A * B+10.18* A * C+5.97 * A * D+7.25* B * D-9.54* B^2-9.11* C^2-9.54* D^2 Eq^n(1)
Final equation in terms of coded factors:

MRR=-295.14448+2.41067*ton+9.12300*toff-1.08292*ip-2.14761 * sv-0.070540 * ton * toff+0.015657 * ton * ip+0.023886* ton * sv+0.014506* toff * sv-0.023841 * toff-2.15630E-003 * ip^2-0.015258 *sv^2 Eq^n (2)

From Eq. 2, it is concluded that the main effects of Ton, IP,SV two-factor interaction between Ton and Toff, Ton and IP, Ton and SV, Toff and SV, and IP and SV have significant effects on MRR

Table 5 : ANOVA for response surface of reduced quadratic model of Material Removal Rate

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	15895.35	11	1445.032	104.6076	<0.0001	**Significant**
A-ton	4134.223	1	4134.223	299.2815	<0.0001	
B-toff	21.93869	1	21.93869	1.588169	0.2393	
C-ip	2836.468	1	2836.468	205.3354	<0.0001	
D-sv	879.9852	1	879.9852	63.7032	<0.0001	
AB	659.5372	1	659.5372	47.74471	<0.0001	
AC	828.6113	1	828.6113	59.98419	<0.0001	
AD	118.1599	1	118.1599	8.553737	0.0169	
BD	174.3185	1	174.3185	12.61913	0.0062	
B^2	1364.956	1	1364.956	98.81086	<0.0001	
C^2	1245.77	1	1245.77	90.18281	<0.0001	
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	
D^2	1364.956	1	1364.956	98.81086	<0.0001	
Residual	124.3245	9	13.81383			
Lack of Fit	45.17862	5	9.035724	0.456662	0.7937	**not significant**
Pure Error	79.14584	4	19.78646			
Cor Total	16019.67	20				

Std. Dev.	3.716696		**R-Squared**	0.992239
Mean	38.77881		**Adj R-Squared**	0.982754
C.V. %	9.584348		**Pred R-Squared**	0.968275
PRESS	508.2247		**Adeq Precision**	37.00546

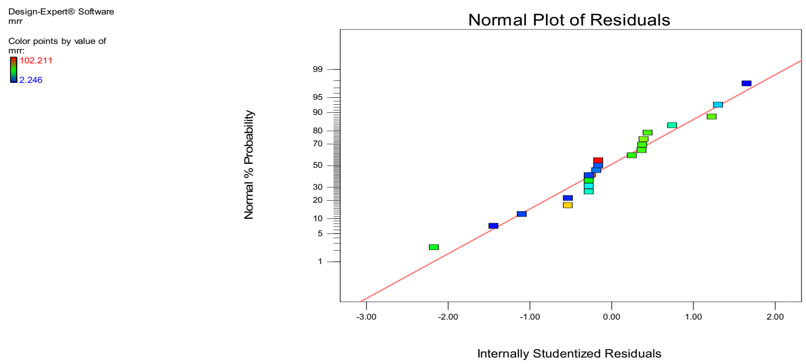

figure 3 : Normal Probability Plot Of Residuals For MRR

B. Effect Of Process Parameter On MRR

The effect of two control factors or process parameters on the response variables is called the interaction effect. For the interaction plot, the two parameters vary keeping other two process parameters at the central value and observe the effect on the response characteristics. This plot is called the three-dimensional surface plot (i.e., 3D surface plot). So the significant interactions are shown in Figs. 4.1(a,b,c,d)

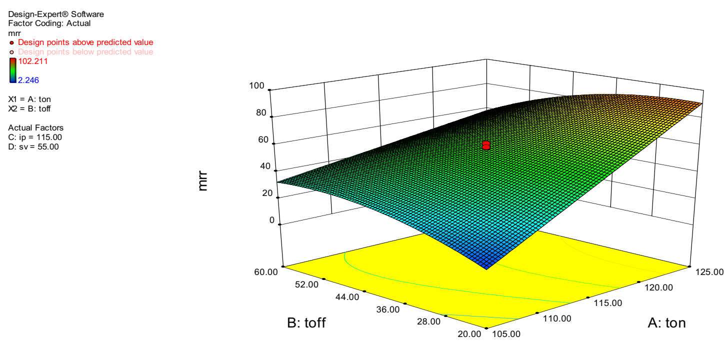

Figure 4.1(a)shows the interaction effect of Ton and Toff

The interaction effect (combined effect) of Ton and Toff on MRR (as shown in Fig.4.1 (a))shows that MRR goes to a maximum value 90.023 mm³/min at a high value of Ton (125) and a low value of Toff (20), while it reaches at a minimum level, where Ton is minimum (105) and Toff is maximum (60). This is due to the fact that higher Ton and lower Toff means that discharge will take place for a long time, long time of discharge means a higher value of discharge energy. A higher value of discharge energy creates violent sparks between the work piece and moving electrode, these sparks causes a faster erosion of material and a faster cutting speed is observed.

The 3d interaction plot of ton and ip is shown in figure below FIG.4.1 (b).

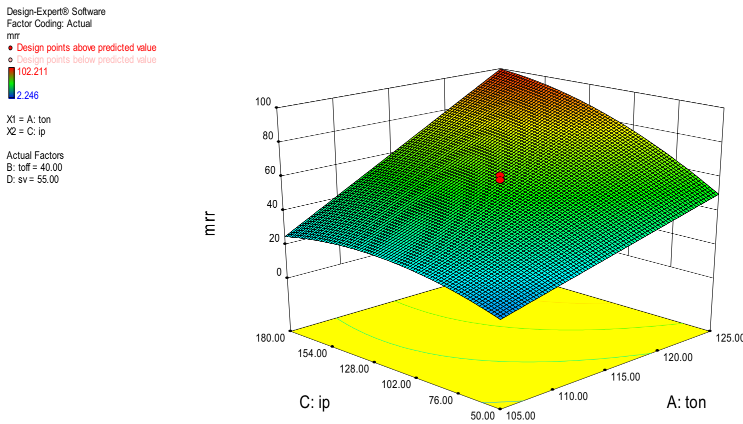

FIG.4.1 (b) : Interaction effect of Ton and Ip

FIG. 4.1b shows that MRR attains a maximum value of 100 mm³/min at a higher value of Ton (125) and higher IP value (180). The effect of Ton is already explained (i.e., higher Ton is essential for better MRR). If IP is more, then it means that discharge energy is more, which results for a better MRR. But the sensitivity of the peak current setting on the cutting performance is stronger than that of the pulse on time. While the peak current setting is too high, wire breakage may occur frequently

Figure 4.1 (c) shows the 3D interaction plot of Ton and Sv on MRR.

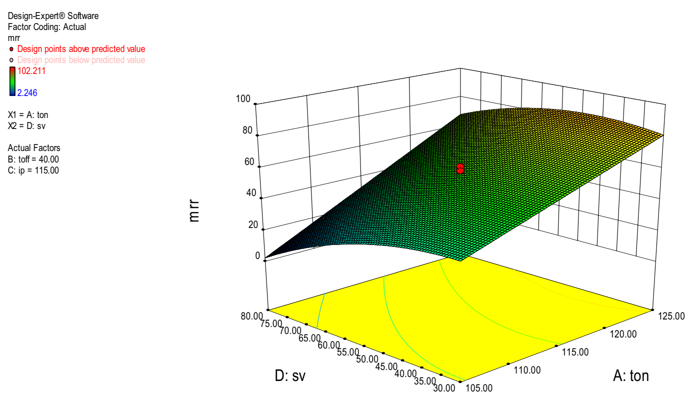

FIG.4.1 (c) : Interaction effect of Ton and Sv

fig. shows that MRR attains a maximum value of 68 mm³/min at a higher value of Ton (125) and higher Sv value (80). The effect of Ton is already explained (i.e., higher Ton is essential for better MRR). MRR increases with decrease in the Spark Gap Voltage (SV).The main reason behind this is, higher the Spark Gap Voltage longer the discharge waiting time. To obtain the longer discharge wait time machining speed needs to be slowed down. So lower value of SV favours the productivity.

IV. CONCLUSION

In this paper, effect of process parameters on MRR is investigated.
it is concluded that:

1. For material removal rate Ton is the most significant process parameter.
2. For both the response parameters, the predicted values of the responses are in close agreement with experimental results.

3. For material removal rate, the main effects of Ton and Toff are the most significant process parameters. SV, IP, quadratic function of Toff, two-factor interactions of Ton and Toff, and Ton and Ip play a significant role for response variable. Quadratic function of Ton and SV, interaction effects of Toff and SV, Ton and IP, and SV and Toff are non significant for material removal rate.

REFERENCES

[1] P.C.Pandey, S.T. Jilani (1984), "Experimetnal investigations into the performance of water as dielectric in EDM", International Journal of Mechanical tool, 24(1), 31-43.

[2] T.A. Spedding and Z.Q. Wang. Parametric optimization and surface characterization of wire electrical discharge machining process. *Precis. Eng.* 20(1): pp.5-15, 1997.

[3] Kansal, H.K., Singh, S. and Kumar, P. (2005) 'Parametric optimization of powder mixed electricaldischarge machining by response surface methodology', *Journal of Materials ProcessingTechnology*, Vol. 169, No. 3, pp.427–436.

[4] S.S. Mahapatra and Amar Patnaik. Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method, Int J Adv Manuf Technol 34, pp. 911-925, 2007.

[5] Hari S, Rajesh Kumar Parametric optimization of Cryogenic treated D-3 for cutting rate in wire electrical discharge machining. *J Eng Technol* 1(2):59–64

[6] Jangra Kamal, Jain.Ajay and Grover Sandeep., (2010). Optimization of multiple-machining characteristics in wire electrical discharge machining of punching die using grey relational analysis. *Journal of Scientific & Industrial Research,* 69, 606-612.

[7] P. Gupta,R. Khanna,R. D. Gupta and N. Sharma, "Effect ofPprocess parameters on kerf width in WEDM for HSLA using Response surface methodology", journal of engineering and technology, vol. 2, pp.1-6, 2012

[8] N. Sharma, R. Khanna, R.D. Gupta, R. Sharma, Modeling and Multi-response optimization on WEDM for HSLA by RSM, Int Journal Adv. Manuf. Technol, august 2013.volume 67,issue 9-12,pp 2269-2281.

[9] Pujari Srinivasa Rao et al. / International Journal of Engineering Science and Technology Vol. 2 (12), 2010, 7729-7739

[10] Box, G.E.P., and Hunter, J.S. (1957), "Multifactor experimental design", J. Ann. Math. Statistics, 28.