Optimization of Cutting Rate for EN 1010 Low Alloy Steel on WEDM Using Response Surface Methodology

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Abstract— *EN 1010is a low-carbon steel alloy with 0.10% carbon content. It is known for its fairly low strength and low ductility; however, it can be tempered to increase strength. Machinability of EN 1010 carbon steel is measured to be fairly good. EN 1010 is commonly used for cold headed fasteners, rivets and bolts, in addition to structural, construction and automotive applications such as fenders, pans, nails and transmission covers. Wire Electric Discharge Machine (WEDM) seems to be a good option for machining the complicated profiles. This paper, find effects of various process parameters of Wire EDM such as pulse on time (Ton), pulse off time(Toff), peak current (Ip) and servo voltage (Sv) for analysis of cutting rate (CR) while machining EN 1010. Central Composite Design is used to plan the design of experiment. The output response variable being cutting rate will be measured for all number of experiments conducted. The optimal parameter level combination would be analysed which gives desired cutting rate. These optimized values of different parameters would then be used in execution the machining operation in order to obtain the necessary outputs.*

Keywords—CCD,Cutting Rate, EN 1010, Process Parameters, RSM,Wire EDM.

I. INTRODUCTION

The main objective of this paper is to study different parameters like(T_{on},T_{off},S_v,W_f) of WEDM operations usingresponse surface methodology, in particular central composite design (CCD), to develop empirical relationshipsbetween different process parameters and output response namely CR. The mathematical models so developedareanalysed and optimised to yield values of process parameters producing optimal values of output response.

II. LITERATURE REVIEW

Puri A.B. and B. Bhattacharyya [1] (2001) study was considered all the control parameters for the machining operation which comprised the rough cut followed by the trim cut. The objective of the study has been carried out experimental investigation based on Taguchi method involving thirteen control factors with three levels for orthogonal array L_{27}. The main factors are finding for given machine were average cutting speed, surface finish and geometrical inaccuracy were caused due to wire lag and also considered the optimum parametric settings for different machining situations have been found and selected the most appropriate cutting parameter combination for Wire Electrical Discharge Machining process to get the required surface roughness value of machined work pieces.

Hewidy M.S et al. [2] (2005) study the development of the mathematical models for relating the relationships of the various Wire EDM machining parameters of Inconel 601 material i.e. Peak Current, Water Pressure and Wire Tension on the Wear Ratio, Material Removal Rate and Surface Roughness. This work was used as Response Surface Methodology. Wire EDM process has shown its competence to machineInconel601 material under the acceptable condition of volumetric material Removal Rate which reached to 8mm^3/min and Surface Finish less than 1μm.

Jinyuang et al. [3] (2007) discuss the development of reliable /multi objective optimization based on Gaussian process regression (GPR) to optimize the parameters of WIRE EDM. The process parameters were mean rate, pulse on time, pulse off time and the output parameters are MRR and surface roughness. The objective function was determined by the predictive reliability with a multi objectives were made by probabilistic variance of the predictive response used as empirical reliability measurement and responses of GPR models. The experiment result shows that GPR models advantage over other regression models in terms of model accuracy. The experimental optimization shows that the effectiveness of controlling optimization process to produce more reliable solution.

Andromeda T. A et al. [4](2011) studied to finding the Material Removal Rate in the Electrical Discharge Machining using the Artificial Neural Network technique. The result of 18 experimental runs to find out the cutting velocity and surface finish collected from the Die Sinking EDM process for the copperelectrode and the steel work piece. It was targeted to develop a behavioural model making use of input-output pattern of the raw data from the EDM process experiment. The use was made of behavioural model to predict the MRR and then the predicted value of MRR was compared to the actual value of MRR. The results showed a good harmony of predicting the MRR between them.

Jaganjeet Singh and Sanjeev Sharma [5] (2013) investigate the effects of various WEDM process parameters on the machining quality and to optimize the response variables of WEDM. The work related to effects of various process parameters of WEDM like T_{on}, T_{off}, Servo voltage (S_v), I_p, Wire feed (W_f) and Wire tension (W_t) have been investigated to demonstrate the influence on material removal rate of P20 Tool Steel by using Elektra Sprint cut 736 WEDM machine. Where the surface roughness was measured by Mar Surf PS5 roughness measuring instrument. The experiments were used by Taguchi methodology (L18) Orthogonal Array and results of the experimentation were analysed by MINITAB software.

H.V.Ravindra et al. [6] (2014) study outlines the development of model to optimize the WEDM machining parameters using the Taguchi's technique which was based on the robust design. Experimentation was performed as per Taguchi's L16 orthogonal array. Each experiment has been performed under different cutting conditions of pulse-on, pulse-off, current, and bed speed. Molybdenum wire having diameter of 0.18 mm was used as an electrode. Three responses have been considered for each experiment namely accuracy, surface roughness, volumetric material removal rate. Based on this analysis, process parameters were optimized. ANOVA was performed to determine the relative magnitude ofeach factor and responses was done using artificial neural network.

F. Klocke et al. [7] (2016) paper study the effect of different annealing and heat treatment processes of 42CrMo4 (AISI 4140) on the S-EDM process. Hence, changes of state variables depending on different machining parameters and were considered. Therefore, the resulting microstructures were analyzed by scanning electron microscope (SEM). Additionally, residual stress was determined and compared to the initial state. The identified changes of investigated state variables were the described modifications.

Amit. R Choudhary and P Shende [8] (2017) objective of this research was to investigate and predict the impact of the electrical parameters: peak current (I), pulse duration (Ton) and pulse off (Toff) on the surface roughness (SR), Cutting time (CT). Adaptive Neuro-Fuzzy Inference System (ANFIS) as one of the active methods and also a set of new data was obtained with different levels. The results indicate that even with the complexity of the EDM process, the Adaptive Neuro-Fuzzy Inference System (ANFIS) was found to be adequate in forecasting response variable with high accuracy

III. EXPERIMENT METHODOLOGY

3.1 Machine tool

In this research work, CR is Output characteristics. This output characteristic is studied under varying conditions of input process parameters, which are namely pulse on time (Ton), pulse off time (Toff), peak current (Ip)and servo voltage (Sv). The experiments were performedon Electronica Sprintcut 734 CNC Wirecut machine as shown in figure 3.1. Electronica Sprintcut734 provides full freedom to operator in choosing the parameter values with in a wide range. A brass wire of0.25 mm diameter is used as the cutting tool material. Deionized water is used as dielectric, which flush away metal particle from the workpiece.

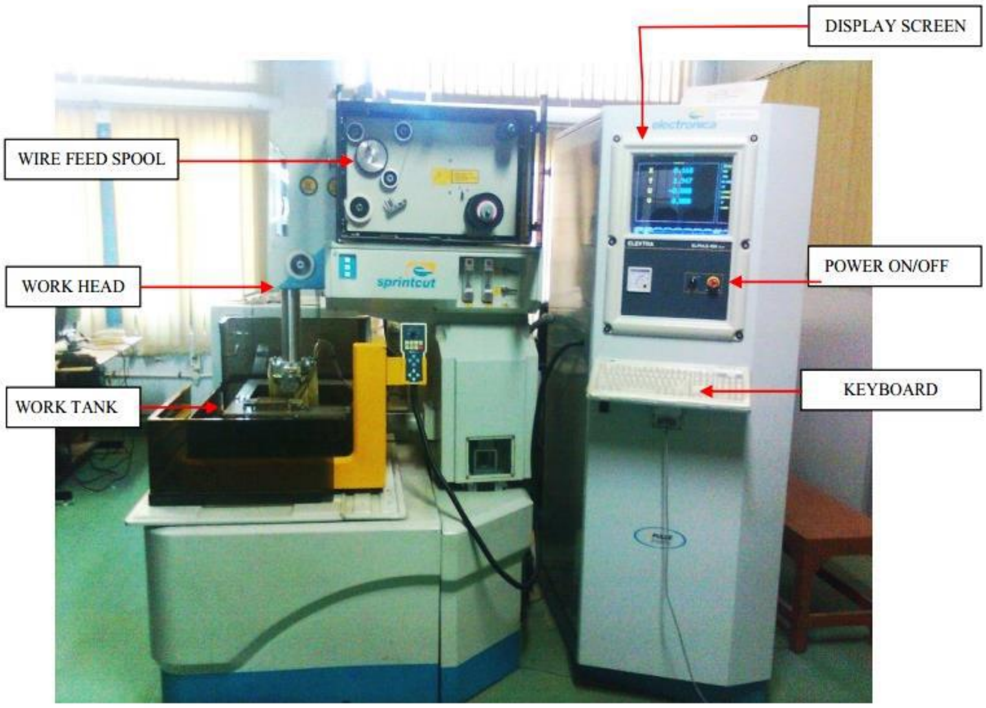

Fig.3.1: Electronica Sprintcut 734 CNC wire cut machine and its parts

3.2 Material

EN 1010 is a low-carbon steel alloy with 0.10% carbon content. It is known for its fairly low strength and low ductility; however, it can be quenched to increase strength. Machineability of EN 1010 carbon steel is measured to be equally good. EN 1010 is commonly used for cold headed fasteners, rivets and bolts, in addition to structural, construction and automotive applications such as fenders, pans, nails and transmission covers. Table 3.1 gives the chemical composition of the work material.

Table.3.1: Chemical composition of EN 1010

Element	C	Si	Mn	P	S
% age by Weight	0.1144	0.0908	0.3843	0.04255	0.02170

The work material used is in rectangular form of dimensions as given below. Figure 3.2 shows the workpiece material used for experiment purpose.

Length = 200mm, Breadth = 100mm, Height = 10mm

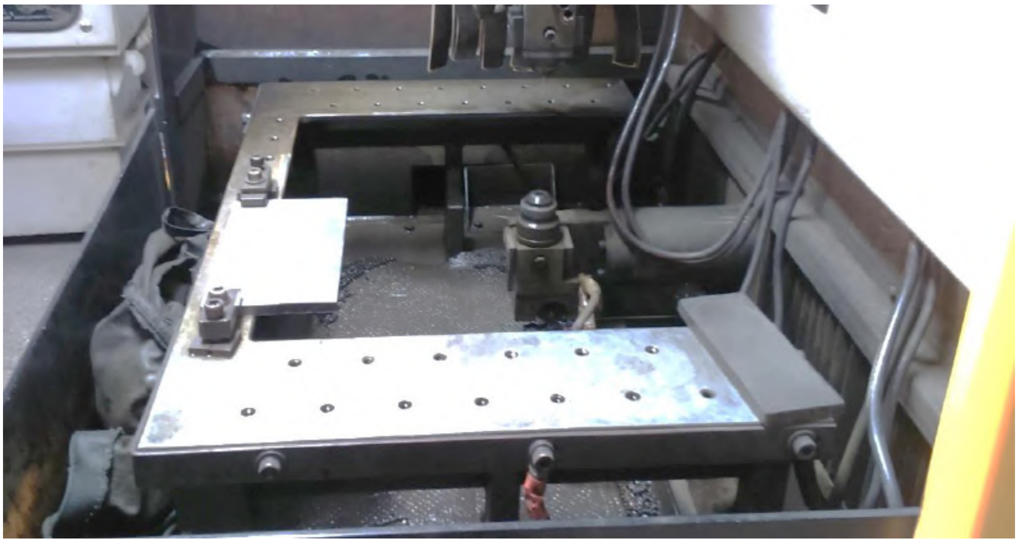

Fig.3.2: EN 1010 workpiece material

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3.2 RSM and Design of Experiment

Response surface methodology is a collection of the statistical and mathematical methods which are useful for the modelling and optimization of engineering science problems. Response surface methodology discovers the relationships between controllable input parameters and obtained Outputs. There are in total 21 experiments carried out according to design of experiments. The average values of CR (mm/min) are shown in Table 3.2.

Table.3.2: Design of Experiment and CR

Run	Ton	Toff	Ip	Sv	CR
1	130	50	80	10	3.68
2	120	30	155	30	3.63
3	110	40	80	10	2.64
4	130	50	230	10	4.99
5	120	40	155	30	3.69
6	120	50	155	30	3.40
7	120	40	230	30	3.67
8	130	30	80	50	4.63
9	120	40	90	30	2.65
10	130	40	155	30	4.26
11	110	30	80	50	2.16
12	120	30	155	50	3.60
13	120	40	155	30	3.65
14	110	40	155	30	2.86
15	120	40	155	10	3.60
16	120	40	155	30	3.85
17	120	40	155	30	3.84
18	110	40	230	10	2.90
19	110	50	230	50	2.86
20	130	30	230	50	3.64
21	120	40	155	30	3.86

IV. RESULT AND DISCUSSIONS

4.1 Analysis of Cutting rate

According to fit summary obtained from analysis, it is found that the quadratic model is statistically significant for CR. The results of quadratic model for CR in the form of ANOVA are presented in Table 4.1.If F value is more corresponding, p value must be less and corresponding resulting in a more significant coefficient. Non-significant terms are removed by the backward elimination for fitting of CR in the model. Alpha out value is taken as 0.05 (i.e.,95 % confidence level). It is found from the Table 4.1 that F value of model is 27.05 and related p value is<0.0001 results in a significant model. The lack of fit is a measure of failure of model to represent data in experimental field at which the points are not included in regression differences in model that cannot be accounted for by the random error. If there is the significant lack off it, as indicated by the low probability value, response predictor is discarded. Lack of fit is non-significant and its value is 5.80.From Table 4.1 it is found that R^2 of model is 0.970641, which is very close to 1. It means that97.06 % variation can be explained by the model and only0.02% of the total variation cannot be explained, which is the indication of good accuracy. The predicted R^2 is in the logical concurrence with adjusted R^2 of 0.238569. Figure4.1 shows normal probability plot of residuals for CR. Most of residuals are found around straight line, which means that the errors are normally distributed. Adequate precision compares significant factors to non-significant factors, i.e., signal to noise ratio. According to results obtained from software, ratio greater than 4 is desirable. In this, adequate precision is 22.943. So, signal to noise ratio is significant. By applying multiple regression analysis on experimental data, empirical relation in terms of actual factors obtained as follows, equation 4.1

$$CR= -4.27428+0.09818*Ton-0.1317*Toff+0.00868*Ip+0.02138*Sv - 0.000254033*Ton^2 - 0.001275*Toff^2 - 0.0000877977*Ip^2 -$$

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0.0014*Sv^2 -0.00005Ton*Ip + 0.00134 Ton *Sv+0.00171*Toff*Ip - 0.0049*Toff*Sv+0.00046Ip*Sv;(4.1)

Table.4.1: ANOVA of Response Surface for cutting rate

Pooled ANOVA for Response Surface Reduced Quadratic Model Analysis of variance table [Partial sum of squares]						
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**P-value Prob> F**	
Model	8.805163	11	0.800469	27.04977	< 0.0001	Significant
A-Ton	1.532993	1	1.532993	51.80349	< 0.0001	
B-Toff	0.041116	1	0.041116	1.389393	0.2687	
C-Ip	1.033738	1	1.033738	34.93246	0.0002	
D-Sv	0.666173	1	0.666173	22.51156	0.0011	
AC	0.450635	1	0.450635	15.22804	0.0036	
AD	0.281203	1	0.281203	9.502527	0.0131	
BC	1.192385	1	1.192385	40.29354	0.0001	
BD	0.483252	1	0.483252	16.33023	0.0029	
CD	0.465452	1	0.465452	15.72873	0.0033	
A^2	0.105407	1	0.105407	26.34125	0.0009	
B^2	0.423345	1	0.423345	16.8713	< 0.0001	
C^2	0.619743	1	0.619743	20.94259	0.0013	
D^2	0.300854	1	0.300854	10.16659	0.0110	
Residual	0.266332	9	0.029592			
Lack of Fit	0.234052	5	0.04681	5.80055	0.0567	Not significant
Pure Error	0.03228	4	0.00807			
Cor Total	9.071495	20				
Std. Dev.	0.172025		R-Squared			0.970641
Mean	3.529524		Adj R-Squared			0.934757
C.V. %	4.873876		Pred R-Squared			0.238569
PRESS	6.907321		Adeq Precision			22.94323

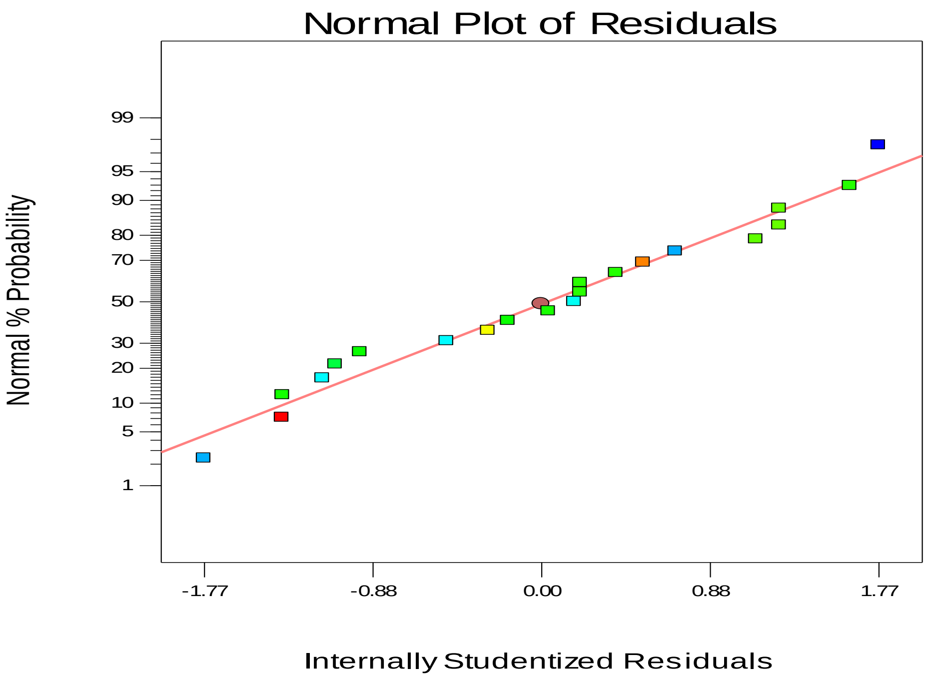

Fig.4.1: Normal plot of residual for cutting rate

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4.2 Effect of Process parameters on Cutting rate

The combined effect of two Process Parameters on Output variables is called interaction effect. For interaction plot, two parameters vary keeping the other two process parameters constant at their central value and observe effect on Output characteristics. This plot is called three-dimensional surface plot. So, the significant interactions are shown in figures 4.2-4.7.

The interaction effect of pulse on time (Ton) and pulse off time (Toff) on cutting rate (CR) is shown graphically in figure 4.2. According to this, cutting rate (CR) attains a peak value of 4.5 mm/min; when Ton is increased from 110 to 130µswith Toff remain unchanged at 30µs. This is because at high value of Ton and corresponding lower value of Toff result in longer duration of spark occur which leads to higher discharge energy subjected on work piece causing faster and greater erosion of material. It also shows that CR attains a minimum value of 2.8 mm/min; when Toff is increased from 30 to 50µs with Ton remain unchanged at 110µs. This is due to the fact that lower value of Ton with a higher value of Toff results in a smaller duration of spark to occur that leads to less amount of release of spark energy causing slower erosion of material.

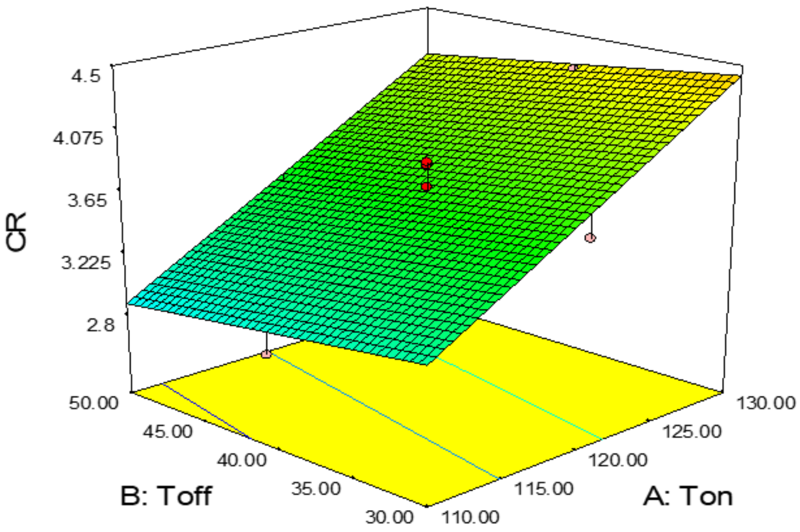

Fig.4.2: Interaction effect of Ton and Toff on cutting rate (CR)

Figure 4.3 shows the interaction effects of pulse on time (Ton) and peak current (Ip) on cutting rate (CR). The cutting rate is increased from 1.3 to 3.65 mm/min when peak current is increased from 80A to 230A with pulse on time remain unchanged at 110 µs.

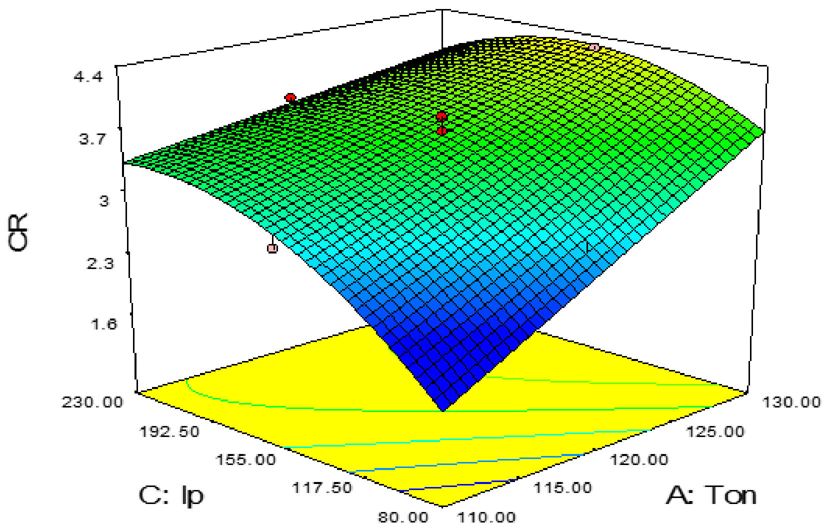

Fig.4.3: Interaction effect of Ton and Ip on cutting rate (CR)

On the other hand, on increasing the pulse on time value from 110 to 130µs the cutting rate increased from 1.3 to 3.65 mm/min with peak current remain unchanged 80A. On setting the pulse on time and peak current to the highest level 130µs and 230A respectively the cutting rate increases to the maximum value of 4.3 mm/min. Increase

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in peak current leads to the increase of the cutting rate. This can be explained by the fact that at higher peak current the pulse energy increases resulting in higher melting and evaporation of the work piece. By increasing the peak current value, the temperature around the spark increases which leads to fast melting of the material at a high rate that increases the cutting rate of the process.

Interaction effect of pulse off time (Toff) and peak current (Ip) on cutting rate (CR) is shown in figure 4.4. When pulse off time is varied from 30 to 50µs, with a constant peak current of 80 A, the cutting rate decreased from 2.58 to 1.2 mm/min.

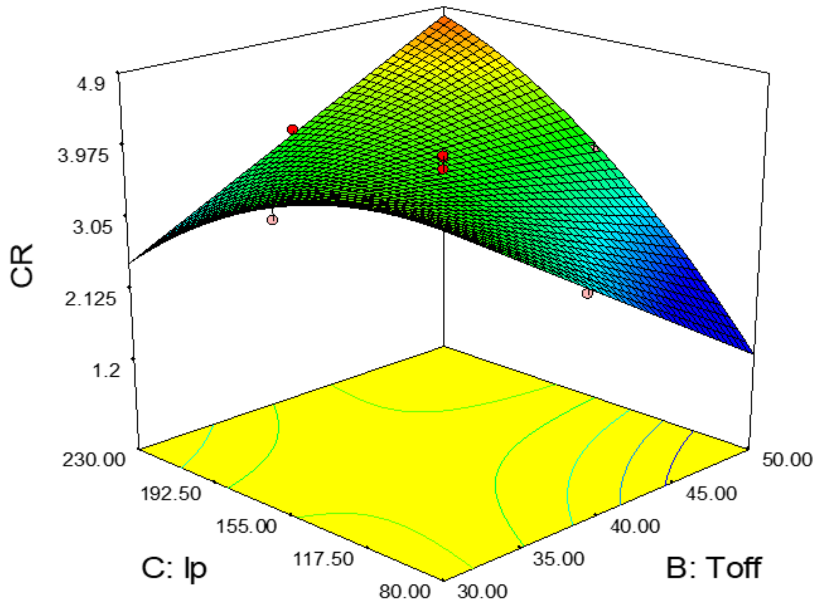

Fig.4.4: Interaction effect of Toff and Ip on cutting rate (CR)

It is due to the fact that on increasing the time gap between the two consecutive sparks the process of erosion of material becomes slow. By increasing the peak current from 80 to 230 A, the cutting rate increased from 2.58 to 4.5 mm/min as on increasing the peak current the pulse energy increases resulting in higher melting and erosion of work piece material.

The interaction effect of pulse off time (Toff) and servo voltage (Sv) (figure 4.5) depicts that a larger cutting rateof 4.5 mm/min is obtained at lower values of Toff (30µs) and Sv (10V) owing to the reasons mentioned earlier. On increasing the values of pulse off time from 30 to 50µs and servo voltage from 10 to 50V the cutting rate decreased to 1.4 mm/min. Sv is the reference voltage in the gap. Higher is the Sv, larger the gap between wire and work piece. It takes a large time for discharge to build up and hence cutting rate need to be reduced by the control system.

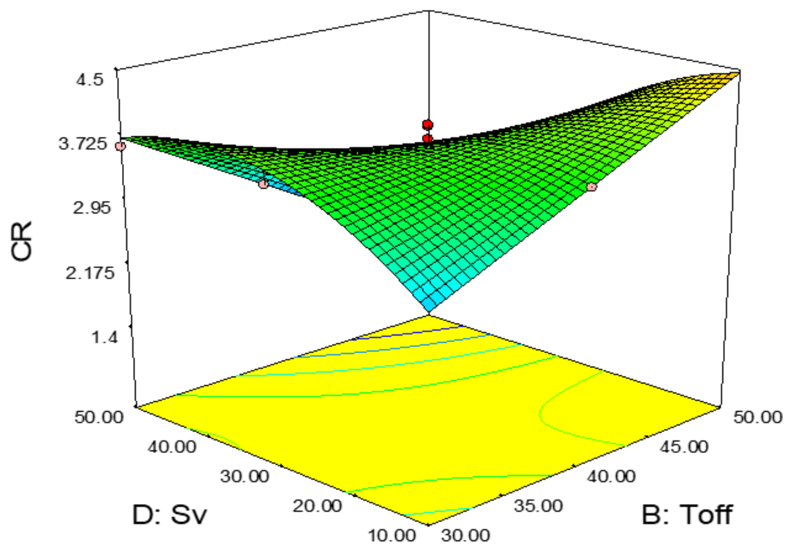

Fig.4.5: Interaction effect of Toff and Sv on cutting rate (CR)

The interaction effect of pulse off time (Ton) and servo voltage (Sv) (figure 4.6) depicts that a larger cutting rateof 4.3 mm/min is obtained at maximum values of Ton (130µs) On increasing the values of pulse on time from 110 to 130 µs so the cutting rate is increased up to 4.3 mm/min. This is because at high value of Ton result in longer duration of spark occur which leads to higher discharge energy subjected on work piece causing faster and greater erosion of material. It also shows that CR attains a minimum value of 1.5 mm/min;when Sv is increased from 10to 50V. Sv is the reference voltage in the gap. Higher is the Sv, larger the gap between wire and work piece. It takes a large time for discharge to build up and hence cutting rate need to be reduced by the control system.

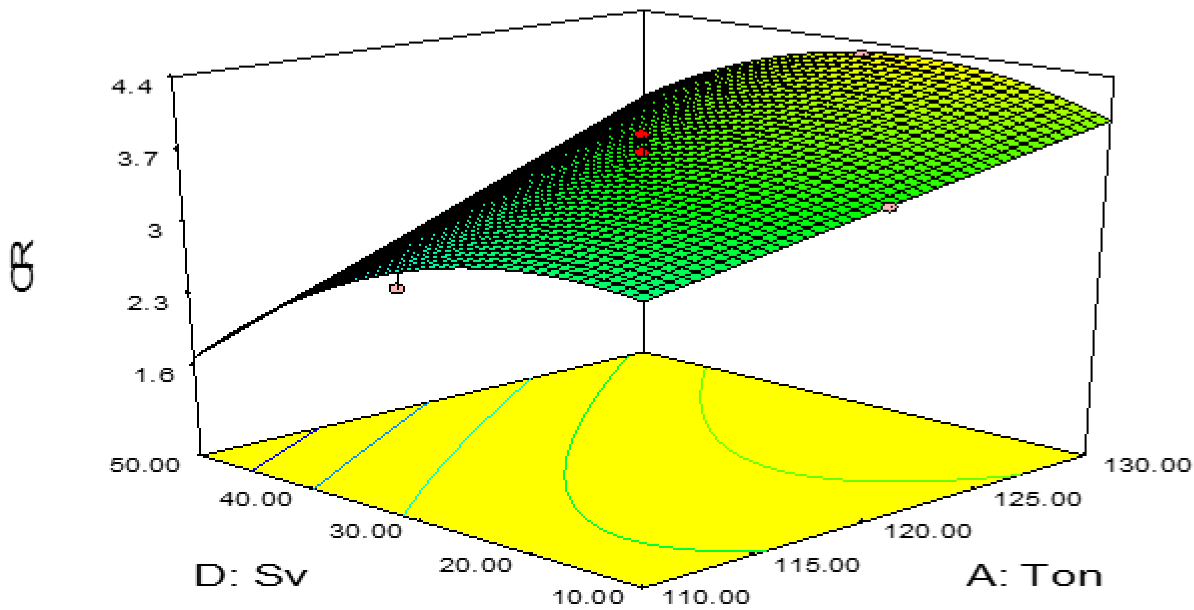

Fig.4.6: Interaction effect of Ton and Sv on cutting rate (CR)

Interaction effect of and peak current (Ip) and Servo Voltage (Sv) on cutting rate (CR) is shown in figure 4.7. When Peak current is varied from 80 to 230A. so the cutting rate is increased from 1.3 to 3.8 mm/min. On increasing the peak current, the pulse energy increases resulting in higher melting and erosion of work piece material and the Servo voltage is increased from 10 to 50 v with cutting rate is decreased from 3.8 to 1.3 mm/min. It is due to the fact that on increasing the time gap between the two consecutive sparks the process of erosion of material becomes slow.

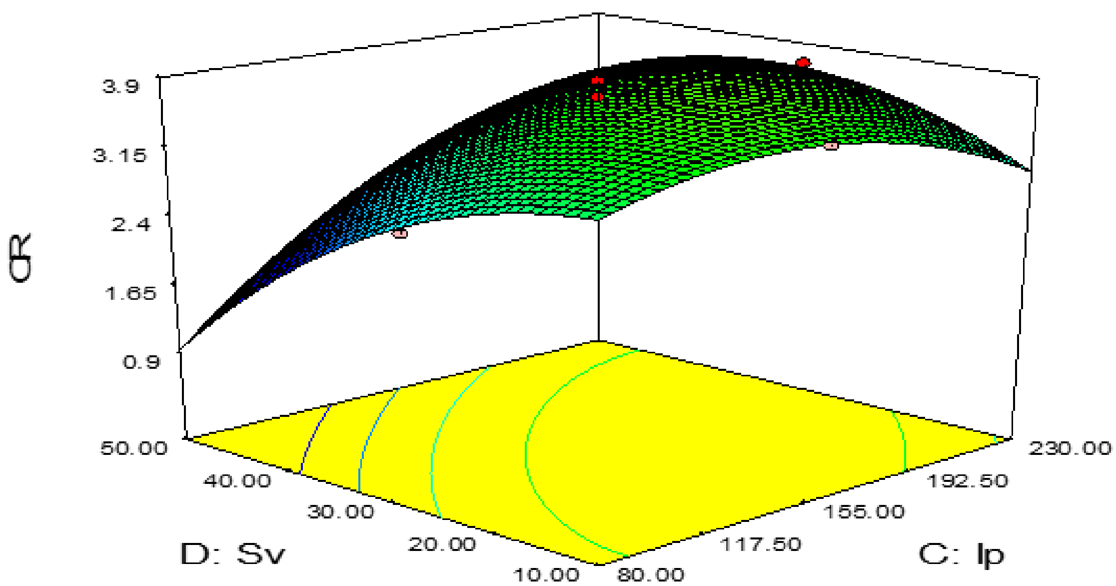

Fig.4.7: Interaction effect of Ip and Sv on cutting rate

V. CONCLUSION

In this paper the effect of Process Parameters on Cutting Rate is optimized, it is concluded that:

1. Main effect of pulse on time, pulse off time, peak current and servo voltage and interaction effect of pulse on time and pulse off time, pulse on time and peak current, pulse off time and peak current, pulse on time and servo voltage,pulse off time and servo voltage, peak current and servo voltage and second order of pulse on time, pulse off time, peak current and servo voltage found to be important from the ANOVA of cutting rate.
2. It was found experimentally and by successive analysis that on increasing the pulse on time and peak current, the cutting rate increases, whereas increasing the pulse off time and servo voltage decreases the cutting rate. The higher discharge energy associated with the increase of pulse on time leads to a more controlling explosion and thus increases cutting rate.
3. For Output parameter, the predicted values of the response are in close agreement with experimental results.

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