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Optimization of Various Machining Parameters of Electrical Discharge Machining (EDM) Process on AISI D2 Tool Steel Using Hybrid Optimization Method

Dr. M.Indira Rani [1] , Ketan[2]
[1]Professor
[2]M.Tech Student
Mechanical Engineering Department, JNTUH College of Engineering, Hyderabad

ABSTRACT

This paper investigates an optimization of various machining parameters of the electrical discharge machining (EDM) processes on AISI D2 tool steel using a hybrid optimization method. Combination of Grey Relational Analysis and Taguchi Method has been proposed to evaluate and estimate the effect of machining parameters on the responses. . The major responses selected for this analysis are material removal rate (MRR) and tool wear rate (TWR), and the corresponding machining parameters considered for this study are pulse current (Ip), pulse duration (Ton), duty cycle (Tau) and discharge voltage (V). The experimental results obtained are used in grey relational analysis, and the weights of the responses are evaluated by using Taguchi Method. The results indicate that the grey relational grade (GRG) was significantly affected by the machining parameters considered and some of their interactions. These results provide useful information on how to control the machining parameters and thereby responses and ensure high productivity and accuracy of the EDM process.

Keywords:- Component, formatting, style, styling, insert.

1. INTRODUCTION

EDM is a thermal process of eroding electrically conductive materials with a series of successive electric sparks and the complex phenomenon involving several disciplines of science and branches of engineering. EDM is one of the most important manufacturing processes extensively useful in the die and mould making industry to generate intricate shape, mould cavity, complex shapes. Its distinctive attribute of using thermal energy to machine electrically conductive materials, regardless of hardness, has been an advantage in the manufacturing of mould, die, surgical, automotive and aeronautic components. It is essential especially in the machining of super tough, hard and electrically conductive materials such as the new space age alloys. It is better than other machining processes in terms of precision, SQ and the fact that hardness and stiffness of a work piece material is not important for the material removal. Though EDM has become an established technology, and commonly used in manufacturing of mechanical works, yet its low efficiency and poor SQ have been the vital matter of concern. Hence, the investigations and improvements of the process are still going on, since no such process exists, which could replace the EDM successfully.

1.1 Working Principle

In EDM, there are two electrodes that are separated by a dielectric fluid. One of the electrodes is called the tool-electrode, or simply the ‘tool’ or ‘electrode’, while the other is called the work piece-electrode, or ‘work piece’. Material removal is based upon the electrical discharge erosion effect of electrical sparks (or discharges) between the two electrodes that are separated at a particular. A series of voltage pulses of magnitude about 5-120 V and frequency of the order of 5 KHz is applied between two electrodes which are separated by a small gap, typically between 0.01 to 0.5 mm. At this small gap, the intensity of the electric field in inter electrode volume become greater than the strength of dielectric, which breaks, allowing the currents to flow between the two electrodes. The intensity of discharges (between the two electrodes) is high enough to generate extremely high temperature (of the order of 8000-12000°C) that melts and evaporate both the electrodes.

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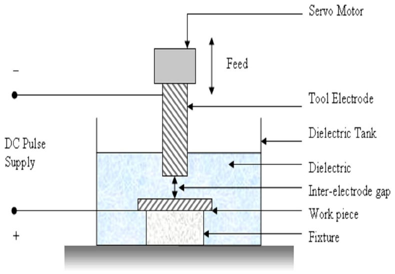

Fig.1 Schematic of EDM tool

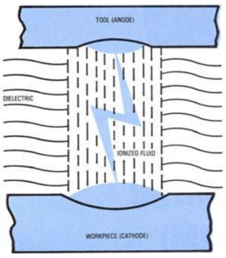

Fig.2 Schematic of Spark generated

Once the current stops, dielectric is flushed into inter electrode volume enabling the solid particles (debris) to be carried away and the insulating properties of dielectric to be restored. This process is repeated very fast as the sparks are generated for a very short duration (between 0.1 to 2000 µs) and thus the machining or material removal takes place. The frequency of discharges or sparks usually varies between 500 and 500,000 sparks per second.

1.2 Parameters of Electro Discharge Machining: There are varieties of parameters that can be used as factor in order to operate EDM Machine the corresponding machining parameters considered for this study were pulse current (Ip), pulse duration (Ton), duty cycle (Tau) and discharge voltage (V).

Pulse Current: Pulse current is the amount of power used in discharge machining, measured in units of amperage. In both vertical and wire applications, the maximum amount of amperage is governed by the surface area of the “cut” the greater the amount of surface area, the more power or amperage that can be applied. Higher amperage is used in roughing operations and in cavities or details with large surface areas. During EDM process, the average current is the average of the amperage in the spark gap measured over a complete cycle. This is read on the ammeter during the process. The theoretical average current can be measured by multiplying the duty cycle and the peak current (maximum current available for each pulse from the power supply or generator). Average current is an indication of the machining operation efficiency with respect to material removal rate.

Pulse Duration Time/Pulse ON time (µs): The whole machining process is carried out during one time. The spark gap is bridged, current is generated and the work is accomplished. The longer the spark is sustained more is the material removal. Consequently the resulting craters will be broader and deeper. Therefore, the surface finish will be rougher. Obviously with shorter duration of sparks the surface finish will be better. With a positively charged work piece the spark leaves the tool and strikes the work piece resulting in the machining. More sparks produce much more wear. Hence, this process behaves quite opposite to normal processes in which the tool wears more during finishing than roughing.

Pulse Off-time (pulse interval time) (µs): It is the duration of time (µ s) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.Arc gap (or gap): It is the distance between the electrode and the part during the process of EDM. It may be called as spark gap

Duty Cycle (Tau): It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time). The result is multiplied by 100 for the percentage of efficiency or the so called duty cycle.

1.3 Measurement of Responses: Material Removal Rate (MRR): MRR is calculated by using the volume loss from the workpiece divided by the time of machining. The calculated weight loss is converted to volumetric loss in cubic millimetre per minute as per Eq. 1:

$$MRR = \frac{\Delta V_w}{T} = \frac{\Delta W_w}{\rho_w g T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{1}$$

Where ΔVw is the volume loss from the workpiece, ΔWw is the weight loss from the workpiece, T is the duration of the machining process and ρwis the density of the workpiece. Tool wear rate:TWR is expressed as the volumetric loss of tool per unittime, expressed as

$$TWR = \frac{\Delta V_t}{T} = \frac{\Delta W_t}{\rho_t g T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2}$$

Where ΔVt is the volume loss from the electrode, ΔWt is the weight loss from the electrode, T is the duration of the machining process and ρt= 8,960 kg/m3 is the density of the electrode.

1.4 Material Selection: There are various combinations of material used for EDM research recently. These researches are using advance material such as super alloy, ceramic, metal matrix composite and etc., on EDM machining. Cost expenditure for these kinds of materials is very high and low availability. Hence, the materials selection for this project is tool steel (AISI D2) for the work piece and Copper electrode will be used.

Table.1 The Physical Properties of Copper Electrode

Physical properties	Value
Electrical resistivity (μΩ/cm)	1.96
Electrical conductivity compared with silver (%)	92
Thermal conductivity (W/mK)	268-389
Melting point (° C)	1083
Specific heat (cal/g ° C)	0.092
Coefficient of thermal expansion (x 10-6 ° C-1)	6.6

Various electrode materials used are graphite, copper, copper graphite, brass, zinc alloys, steel copper tungsten, silver tungsten, tungsten, etc. power supplies. Metallic electrodes, Such as Copper, Brass, Copper, Tungsten, etc. were the only electrode materials that would perform effectively with an R-C (Resistor Condenser) EDM. Besides graphite, copper also has the qualities for high stock metal removal. It is a stable material under sparking conditions. Its wear can be comparable with graphite. Indeed with some work piece materials, it yields a finer surface finish. Copper is easily obtainable, consistent in quality and low in cost. Copper has melting point which is only about 1100°C.

Tool Steel (AISI D2): AISI D2 is one of the most popular high-chromium and high-carbon steels of D series and it is characterized by its high compressive strength and wear resistance, good through - hardening properties, high stability in hardening and good resistance to tempering - back. Cold work tool steels of Series D, also known as die steels, are high alloy steels Fe – Cr -C-base. This alloy has the ability to preserve its desirable mechanical properties intact upon cycling over a range of temperatures, which can be an advantage for applications including, piercing and blanking dies, punches, shear blades, spinning tools, slitting cutters, as well as variety of higher end wood working tools.

Table.2 AISI D2 steel composition

Element	C	MN	Si	Cr	Ni	Mo	V	Co	Cu	P	S
Weight %	**1.4-1.6**	**0.6**	**0.6**	**11-13**	**0.3**	**0.7-1.2**	**1.1**	**1**	**0.25**	**0.03**	**0.03**

2. LITERATURE SURVEY

Kumar et al. [1] compared the performance of copper-chromium alloy with copper and brass as EDM electrode materials for machining OHNS die steel using kerosene and distilled water as dielectric media. Keeping all other machining parameters same, the hardened work material was machined with the three electrodes at different values of discharge current. It was found that copper-chromium alloy shows better results than copper and brass in terms of material removal rate, dimensional accuracy (lateral overcut) and surface finish in both the dielectric media. Tool wear rate of this alloy was lower which results in better accuracy and trueness of the machined profiles because the mirror image of the tool electrode was reproduced in the work piece. Regarding the use of distilled water as a dielectric medium, though material removal rate was low and tool wear rate was high, but hardness and finish of the machined surface showed a marked improvement [1]. Rao et al. [2] Optimized the metal removal rate of die sinking electric discharge machining (EDM) by considering the simultaneous effect of various input parameters. The experiments are carried out on Ti6Al4V, HE15, 15CDV6 and M-250. Experiments were conducted by varying the peak current and voltage and the corresponding values of metal removal rate (MRR) were measured. Multi-perceptron Neural Network Models were developed using Neuro solutions package. Genetic algorithm concept was used to optimize the weighting factors of the network. It was observed that the developed model was within the limits of the agreeable error when experimental and network model results were compared for all performance measures considered. It was further observed that the maximum error when the network was optimized by genetic algorithm reduced considerably. Sensitivity analysis was carried out to find the relative influence of factors on the performance measures. It was observed that type of material is having more influence on the performance measures. Pradhan and Biswas [3] investigated the relationships and parametric interactions between the three controllable variables on the material removal rate (MRR) using RSM method. Experiments were conducted on AISI D2 tool steel with copper electrode and three process variables (factors) as discharge current, pulse duration, and pulse off time. To study the proposed second-order polynomial mode for MRR, the authors used the central composite experimental design to estimation the model coefficients of the three factors, which are believed to influence the MRR in

EDM process. The response was modelled using a response surface model based on experimental results. The significant coefficients were obtained by performing analysis of variance (ANOVA) at 5% level of significance. It was found that discharge current, pulse duration, and pulse off time significant effect on the MRR.

3. EXPERIMENTAL DESIGN

The general scenario in an experiment is that there is an output variable (generally quantitative in nature), which depends on several input variables, called factors. Each factor has at least two settings, called levels. A combination of the levels of all the factors involved in the experiment is called a treatment combination. Design of Experiments (DOE) is a statistical technique used to study the effects of multiple variables on performance measures simultaneously. It provides an efficient experimental schedule and statistical analysis of the experimental results. The optimization procedure for the characteristics features of electric discharge machining of AISI D2 Tool steel through experimental studies. Taguchi-grey relational based multi response optimization technique has been employed for analysis of experimental results. The parameters and levels which have been investigated during the study are given in table 3. The resultant data obtained after performing experimentation is reported in table 4. As the investigation is done on four parameters at four different levels, L16 array is used which means 16 experiment runs have to be conducted for determining optimal set of process parameters.

Table.3 Input variables used in the experiment and their levels

Variable	Unit	Levels		
		1	2	3
Discharge current (Ip)	**A**	**4**	**7**	**10**
Pulse on time (Ton)	**µs**	**100**	**200**	**300**
Duty cycle (Tau)	**%**	**80**	**85**	**90**
Voltage (V)	**Volt**	**40**	**50**	**60**

Table.4 L9 Orthogonal array with experimental values

Expt. No.	Current (Amps)	Pulseon Time (Ton)(µs)	Duty Cycle (Tau)	Voltage (V)	Overall Grey Relational Grade	Rank
1	4	100	80	40	0.4487	7
2	4	200	85	50	0.4122	8
3	4	300	90	60	0.3333	9
4	7	100	85	60	0.4739	6
5	7	200	90	40	0.5798	4
6	7	300	80	50	0.5305	5
7	10	100	90	50	1	1
8	10	200	80	60	0.7830	2
9	10	300	85	40	0.6540	3

Table.5 S/N Ratios Table

Expt. No	Current (Amps)	Pulse On Time (Ton) (µs)	Duty Cycle (Tau)	Voltage (V)	MRR (mm3/min)	EWR (mm3/min)
2	4	200	85	50	6.485	0.028
3	4	300	90	60	3.13	0.011
4	7	100	85	60	6.87	0.089
5	7	200	90	40	16.169	0.07
6	7	300	80	50	13.755	0.05
7	10	100	90	50	26.662	0.647
8	10	200	80	60	24.42	0.208
9	10	300	85	40	21.97	0.06

Calculating S/N ratios: The S/N ratios are determined by characteristics of the machining process. The categories of larger the better, smaller the better and nominal the better are being used to increase material removal rate and to reduce the electrode wear rate.

Normalizing S/N ratios: The S/N ratios obtained from the Taguchi analysis have to be normalized. The original sequence is transferred to a comparable sequence, where the original data normalize to a range of 0 and 1.

Table.6 Normalized values of S/N ratios **Table.7** Grey Relational coefficient of MRR and SR (φ =0:5.)

Expt. No.	**Normalized S/N ratios of MRR.**	**Normalized S/N ratios of EWR**
1	0.2851	0.4711
2	0.3400	0.2293
3	0	0
4	0.3699	0.5131
5	0.7665	0.4541
6	0.6910	0.3716
7	1	1
8	0.9589	0.7214
9	0.9096	0.4163

Expt. No.	**Current (Amps)**	**Pulse on Time Ton (µs)**	**Duty Cycle (Tau)**	**Voltage (V)**	**S/N ratio of MRR**	**S/N ratio of EWR**
1	4	100	80	40	15.2175	22.4988
2	4	200	85	50	16.2382	31.0568
3	4	300	90	60	9.9109	39.1721
4	7	100	85	60	16.7391	21.0122
5	7	200	90	40	24.1737	23.0980
6	7	300	80	50	22.7692	26.0206
7	10	100	90	50	28.5179	3.7819
8	10	200	80	60	27.7549	13.6387
9	10	300	85	40	26.8366	24.4370

Generating Grey relational coefficient: After normalizing the data, usually grey relational coefficient is calculated to display the relationship between the optimal and actual normalized experimental results.

Table.8 Grey Relational Grades

Expt. No.	**Grey Relational coefficient of MRR**	**Grey Relational coefficient of EWR**
1	0.4115	0.4859
2	0.4310	0.3934
3	0.3333	0.3333
4	0.4412	0.5066
5	0.6816	0.4780
6	0.6180	0.4431
7	1	1
8	0.9240	0.6421
9	0.8468	0.4613

Generating Grey Relational Grade: The grey relational grade γ, indicates the level of association between the reference sequence and the comparability sequence. A higher grey relational grade value infers a stronger relational degree between the comparative and referential (ideal) sequence.

4. RESULTS AND DISCUSSIONS

Based on the above discussion, the optimal operational conditions established by grey analysis approach are as follows: a pulse current 10 A, pulse duration 100 µs, duty cycle 90 % and discharge voltage 50 V. Therefore, experiment 7 shown in Table 4 fits the optimal process conditions. The effect of each machining parameter on the GRG at different levels can be independent. The mean of the GRG for each level of the EDM process parameters is presented in Table 9.

Table.9 Main Effects of process parameters on the Grey Relational Grade

Level	**Current**	**Pulse on Time**	**Duty Cycle**	**Voltage**
1	0.3980	0.6408	0.5874	0.5608
2	0.5280	0.5916	0.5133	0.6475
3	0.8123	0.5059	0.6377	0.5300
Delta	0.4143	0.1349	0.1244	0.1175
Rank	1	2	3	4

Fundamentally, the larger the GRG, the better is the multiple performance characteristics. Conversely, the relative importance among the EDM process parameters for the multiple performance characteristics still needed to be investigated so that the optimum combination of the EDM process parameter levels can be decided more correctly. Fig.3 displays the variance of GRG throughout the experimental runs. Wherever there is a large slope in the figure, it could be inferred that the parameter has a significant influence on the EDM process. In this study, it can be visually understood and found that Ton and Ip have a significant effect. Figures 3 to 4 depict the plots of the main effects on GRG, and those can be used to graphically assess the effects of the factors onthe response. It Indicates that Ton and Ip have a significant effect on GRG; however, Ip is the most influencing machining parameter.

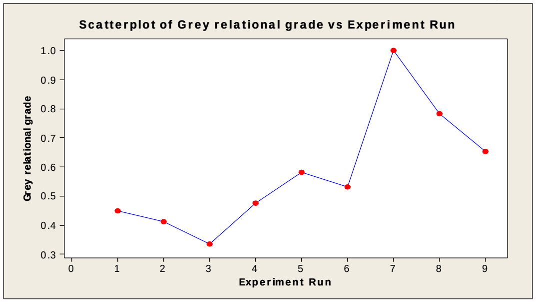

Fig.3 Grey Relational Grades for Maximum MRR and Minimum Ra

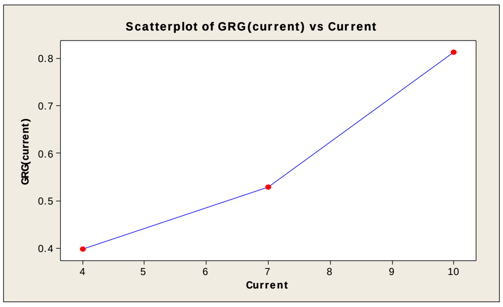

Fig .4 Grey relational grades for each level of Current

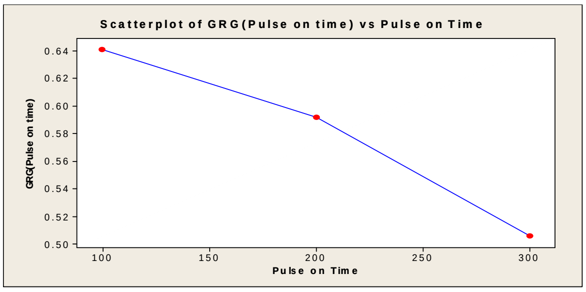

Fig.5 Grey relational grades for each level of pulse on *t*ime

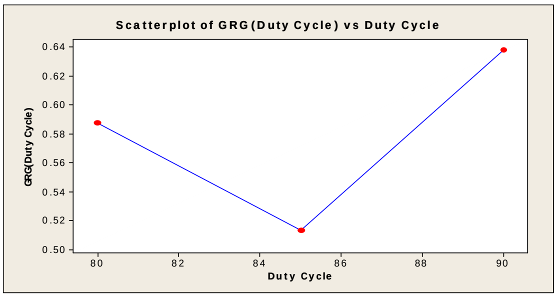

Fig.6 Grey relational grades for each level of duty cycle

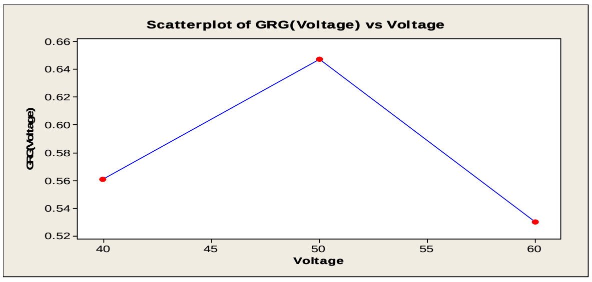

Fig.7 Grey relational grades for each level of Voltage

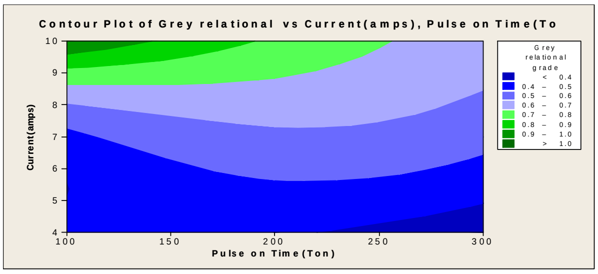

Fig.8 Two-dimensional contour plots for GRG Effect of a pulse current and pulse on tim

With GRG as the response, the contour plots of the model keeping two variables at their mean levels and varying the other two within the experimental ranges are, separately, shown in Fig.11. The shapes of the contour plots may be curvature with circular, elliptical or saddle implying whether the interactions between the variables are significant or not. The contour plot in Fig.8 shows that the interactive effects of Ip and Ton on GRG were significant. The surface plot of the significant factors are also exhibited in Figs.9,10&11, respectively, for the interactive effect of Ip×Ton, Ip×V and Tau×V, respectively, keeping the other factors at their mean level.

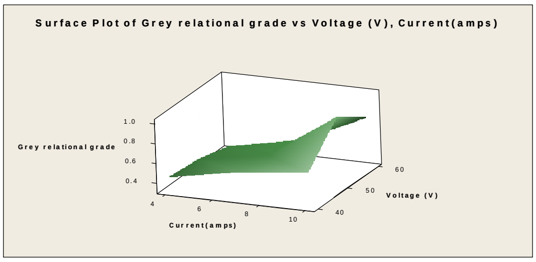

Fig. 9 Response surface plot representing the effect of Ip and V on GRg.

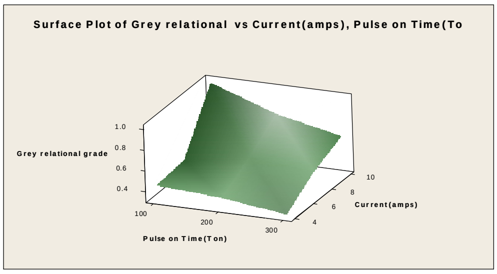

Fig.10 Response surface plot representing the effect of Ton and Ip on GRG

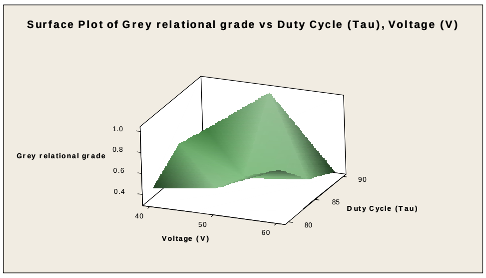

Fig.11 Response surface plot representing the effect of V and Tau on GRG

Effect of process parameters on Material Removal Rate (MRR): The below four graphs illustrates the effect of the process parameters i.e. current, pulse on time, pulse off time and voltage on MRR. As MRR is important factor to measure the productivity of a particular process so it is important to know the effects of various process parameters on it.

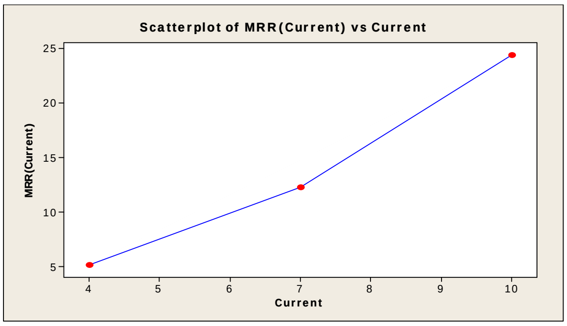

Fig.12 Material Removal Rate for each level of Current

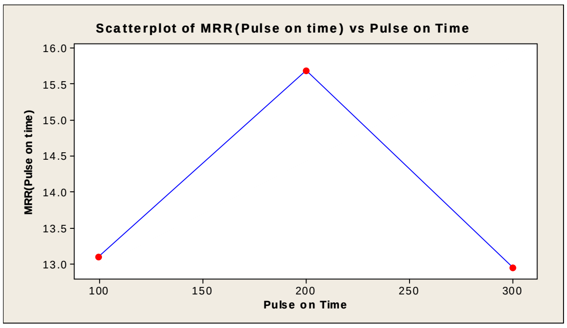

Fig.13 Material Removal Rate for each level of Pulse on Time

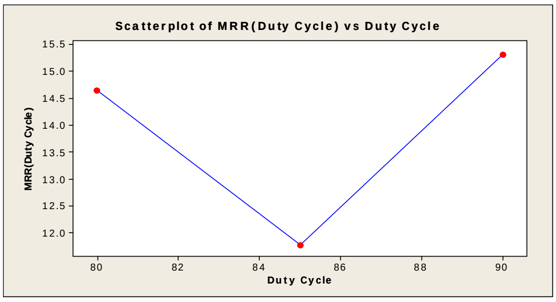

Fig.14 Material Removal Rate for each level of Duty Cycle

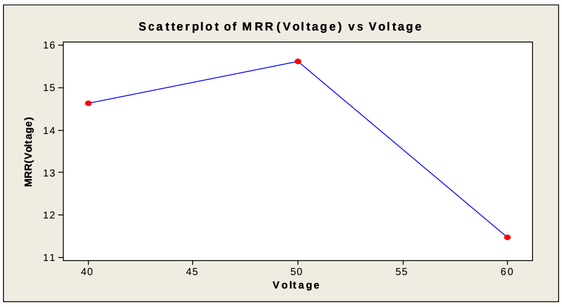

Fig.15 Material Removal Rate for each level of Voltage

Effect of parameters on Electrode Wear Rate (EWR): The following four graphs depicts the effect of the process parameters i.e current, pulse on time, pulse off time and voltage on EWR. As EWR is important factor to measure the productivity and efficiency of a particular process so it is important to know the effects of various process parameters on it.

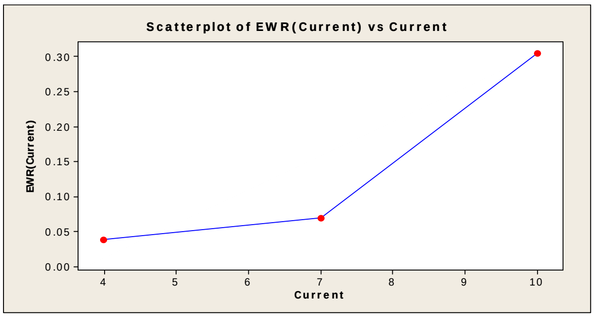

Fig.16 Electrode wear Rate for each level of Current

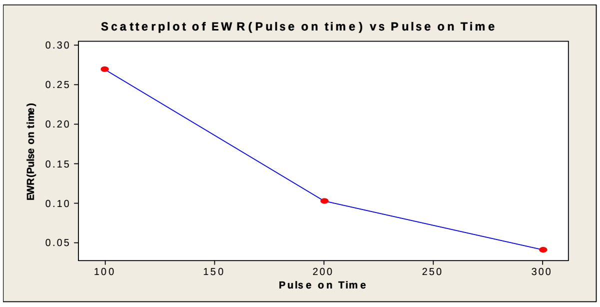

Fig.17 Electrode wear Rate for each level of Pulse on time

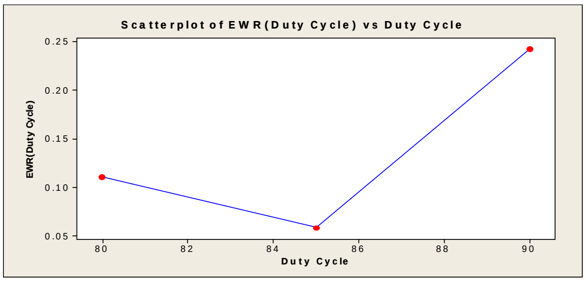

Fig.18 Electrode wear Rate for each level of Duty Cycle

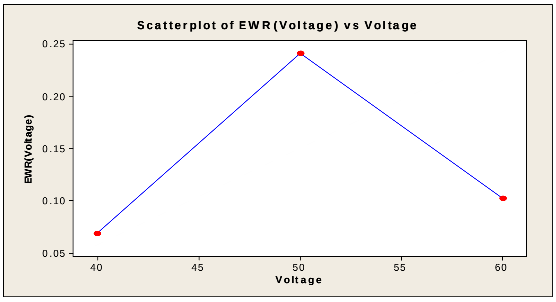

Fig.19 Electrode wear Rate for each level of Voltage

5. CONCLUSION

In this study, Taguchi L9 array with grey relational analysis has been used to optimize the multiple performance characteristics: material removal rate(MRR) and Electrode wear rate(TWR). The largest max-min value has been found from response table. It is found that peak current is most significant factor among process parameters involved in EDM process. Based on the observations from the experimental runs, the following conclusions are presented: With increase in current, the value of MRR and EWR gradually increased. So in order to have an optimal condition (high MRR and low EWR), we have to choose moderate current. With increase in pulse ON time, the value of MRR first increased and then gradually decreased after level 2(200 µs) but the value of EWR gradually decreased from level 1(100 µs) to level 4(75 µs). With increase in pulse Duty Cycle, the value of MRR fluctuated throughout the levels, it first decreased and then finally increased, whereas the value of EWR gradually decreased till level 2 and then steeply increased. With an increase in voltage, the value of MRR first dramatically increased and then plummeted downwards at level 2(50V), however, the value of SR gradually increased from level 1(40V) to level 2(50V) and gradually decreased from level 3(50V) to level 4(60V). Optimum parameter settings obtain from Grey Relational analysis are Current (10A), Pulse ON Time (100 µs), Duty Cycle (90%) and Voltage (50 V). This study will help in identifying the significant factors which are efficiently regulated to decrease error, time consumption and cost and to increase quality and productivity. This study may provide the experimenter and practitioners an effective guideline to select optimum parameter settings for achieving the desired MRR, TWR and G during EDM of AISI D2 tool steel. This method can also be applied for the optimization of the processing parameters in other manufacturing processes, to promote manufacturing efficiency.

REFERENCES

[1].S Kumar, TP Singh (2007), "A comparative study of the performance of different EDM electrode materials in two dielectric media", (IE) (I) Journal- PR, Vol. 8, PP. 38.
[2].SK Saha (2008), "Experimental investigation of the dry electric discharge machining (Dry EDM) process", M. Tech. Thesis, IIT Kanpur, Kanpur 208016, India.
[3].GKM Rao, GR Janardhana, DH Rao, MS Rao (2008), "Development of hybrid model and optimization of metal removal rate in electrical discharge machining using Artificial Neural Networks and Genetic Algorithm", ARPN Journal of Engineering and Applied Sciences, Vol. 3, No. 1, pp. 19-30.
[4].MK Pradhan, CK Biswas (2008), "Modeling of machining Parameters for MRR in EDM using response surface methodology", Proceedings of NCMSTA' 08 Conference (National Conference on Mechanism Science and Technology, from Theory to Application), November 13-14, 2008, NIT Harripur, India.

[5].W Tebni, M Boujelbene, E Bayraktwe, S Ben Salem (2009), "Parametric approach model for determining electrical discharge machining (EDM) conditions, effects of cutting parameters on the surface integrity", The Arabian Journal for Science of Engineering, Vol. 34, No.1C, pp. 101 114.

[6].Marcel Sabin Popa, Glad Contiu, Grigore Pop, (2009), "Surface quality of the EDM processed materials, XXIX IMEKO World Congress, Fundamental and Applied Metrology, September 6-11, 2009, Lisbon, Portugal.

[7].J Marafona, C wykes (2000), "A new method of optimizing material removal rate using EDM with copper-tungsten electrodes", International Journal of Machine Tools and manufacture, Vol. 40, pp. 153-164.

[8].Yih-fong Tzeng, FU-chen Chen (2007), "Multi-objective optimization of high speed electrical discharge machining process using a Taguchi fuzzy based approach", Materials and Design, Vol. 28, pp. 1159-1168.

[9].H Singh, R Garg, (2009), "Effects of process parameters on material removal rate in WEDM", Journal of Achievement in Materials and Manufacturing Engineering, Vol. 32, No. 1, pp. 70-74.

[10].AKM Asif Iqbal, Ahsan Ali khan (2010), "Modeling and analysis of MRR, EWR and surface roughness in EDM milling through Response Surface Methodology", American Journal of Engineering and Applied Science, Vol. 3,No. 4, pp.611-619