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Optimization of Machining Parameters on Electric Discharge Machining (EDM) of Maraging Steels C300

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Abstract: ***Electric discharge machining is categorized under thermoelectric process in which heat energy of spark is used to remove the material from work piece. This process involves controlled deterioration of electrically conducting material by the initiation of rapid and repetitive electrical spark discharges among tool and work piece, which are divided by dielectric. The present thesis aimed that is to characterizing the electric discharge machining parameters of maraging steels 300 on EDM by using Graphite as a electrode. Total 9 experiments are performed according to L9 orthogonal array and optimized values are obtained from Taguchi analysis. The Machining is executed by varying EDM process parameters such as pulse off time, current and pulse on time. The outputs are measured like material removal rate and surface finish are assessed. It is found that metal removal rate and surface roughness are increasing with increasing current and pulse on time.***

Keywords: spark, dielectric, maraging steels, EDM, Graphite, Taguchi analysis

1. Introduction

The aim of any machining process is to machine the extra material to obtain the recommended size and shape. These operations use different forms of energies like chemical, electrical, mechanical, etc. The non-traditional machining processes are having several advantages over conventional machining processes. These methods are applicable to all materials which may be hard, brittle and high toughness. However unconventional machining process is not a substitute for conventional machining methods, but is only complementing them. All the methods are not applicable for every the materials.

1.1 Electrical Discharge Machining Process

Electro Discharge Machining delivers high frequency sparks for machining hard materials & contours. The average gap maintained among the tool and work piece is 20 to 200µm in dielectric medium though which the spark discharge occurs. There are two forms of EDM techniques are there .In one, the tool is kept rigid and preformed to shape of the desired contour of the machined surface. This process is known as sinking type EDM. The other process employs a flexible wire of less than 0.25 mm diameter as the electrode, continuously passing though the machining zone of work piece. In SEDM machine kerosene used as dielectric fluid and In WEDM machine demineralised water is used as medium.

1.2 Principle and Description of EDM Process

The material deterioration mechanism primarily makes use of electrical energy and which is converted into thermal energy through a sequence of different electrical discharges developing among work piece and electrode are dipped in a dielectric. The thermal energy generates a channel of plasma between the cathode and anode at temperature range of 8,000 to 12,000^{0}C or as high as 20,000^{0}C initializing a substantial amount of heating and melting of material at the surface of each pole. When highly pulsating current supply developing nearly at a rate of 20-30K Hz is turned off, the plasma channel breaks down. Which results a sudden depletion in the temperature and allows the flow of dielectric fluid to push the plasma channel.

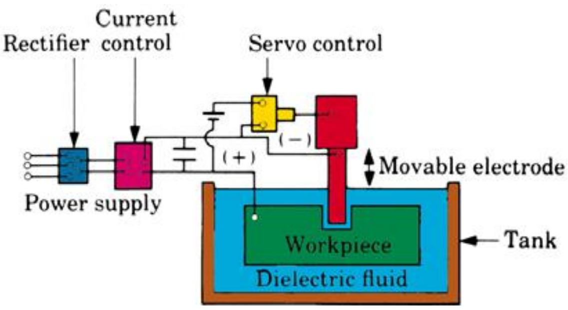

Figure: 1 Basic elements of SEDM

2. Literature Survey

A serious amount of work has been focused to find optimal EDM performance measures of high metal removal rate (MRR) and satisfactory surface roughness (SR). Guo studied the mechanism of EDM combined with ultrasonic vibrations of the wire. He established that the combination of EDM and ultrasonic vibrations form the multiple channel discharge and raises the utilization ratio of the energy that results that the improvement in cutting rate and surface finish. Highly frequenced vibrations of electrode reduce the possibility of rupture electrode and improve the removal concentration. Guo established that with the help of ultrasonic, the cutting speed of wire EDM can be increases by 30% and surface of the machined reduces from 1.96Ra to 1.6Ra [1]. Kunieda and Furudate are conducted research on dry EDM.In this process the reaction force is very small and negligible. As compared with the conventional EDM, the vibrations of the wire electrode is very less and the gap among work and electrode in dry EDM is very small. Than the conventional EDM, which results the dry EDM to realize the high precision in finish cutting. There is no oxidation of the work piece, which gives an advantage to dry EDM in manufacturing of high precision molds and dies. These are agreed that EDM is suitable for finishing cut, specifically for correcting the flatness of the machined surface. Machined surface of dry EDM is better than that of the machined surface is removed by using water and also have better straightness .These are found some imperfections in dryWEDM [2]. Joerres and koenig established that, Water with some of additives, gives the advantage over the hydrocarbon mediums when working with long pulse durations and high discharge currents. Pashby and Leao found that some of investigators have studied the optimalitty of adding organic compounds such as polyethylene glycol 200, ethylene glycol, sucrose and dextrose to enhance the performance of ionized water. The machined surface of titanium work piece has been changed after urea solution mixed with water .The nitrogen element dissolved in the dielectric medium that contains urea that means it is migrated in to the work piece, so that it forms a hard layer called titanium nitride. This layer has exceptional wear resistance [3]. The EDM of advanced materials has been widely accepted by the metal cutting industry, because it has their own special properties and features. Dauw and koangare classified different types of grades of engineering ceramics such as conductors, natural conductors and nonconductors. Sanchez et. provided a literature survey on the EDM of advanced materials which has been frequently machined by laser beam machining (or) ultrasonic machining and proved that machining of advanced materials such as Boron Carbide (B4C) and Silicon Carbide (SiC) are also machied by using EDM and wire EDM [4]. A combination of EDM and USM was also examine to enhance the circulation of dielectic medium in the spark gap, while machining of advanced materials they are found that significant change in the performance measures and reduction in the thickness of the white layer. A lot of research work is done in case of tool steels, die steels, hybrid composites and ceramics. But available literature on advanced materials such as Ti-6Al-4V and maraging steels (M250) is scanty. The present thesis is concentrated on Maraging steels C300 which are extensively used in pump shafts, shipbuilding, aerospace,, valves, automobiles and heat exchangers etc[5].

3. Problem Definition

The objective of this project is to analyze the effect of current, pulse on time and pulse off time on the machining characteristics (MRR, SF) and optimization of the machining parameters of CNC EDM process to achieve better metal removal rate (MRR) and surface Finish(SF) using Taguchi design method and ANOVA.

Description of work piece material and tool material:
Work piece material: Maraging Steel C300
Dimensions of Work Piece material: 50x50x5mm (1 pieces)
Electrode material: Graphite
Dimensions of electrode material: 14mm diameter, 80 mm length (2 pieces)

4. Experimental Setup

The experiments are conducted to find the effects on the various machining input parameters on EDM process. These effects have been taken into account to find the effects of current, pulse on time & pulse off time on the MRR and Surface Finish. The Maraging Steels C300 is machined with Graphite electrode. The kerosene water is used as dielectric medium. In this project the outcome of current, pulse on time and Pulse off time on the performance indices of EDM i.e., MRR and surface finish. Total 9 experiments are conducted on Maraging Steel C300 alloy by changing current, pulse on time and off time according to L9 orthogonal array. The important parameter for machining efficiency is the polarity; here the straight polarity is taken as we are working on the material removal rate.

Figure 2: CNC EDM Machine

Table 1: CNC Electric Discharge Machining Specifications

Item	*Units*	*Level – 1*
Maximum output Current	Amps	50
Input Voltage	Volts	220/364/415/440
Maxi consumption rate	Kw	6
Non-load output voltage	Volt	100
ON TIME setting range	Millisecond	1-9,999
OFF TIME setting range	Millisecond	1-9,999
Eroding frequency	Hertz	90-500K
Main power cable	Millimeter	8
Ground cable	Mm	8
Weight	Kg	100

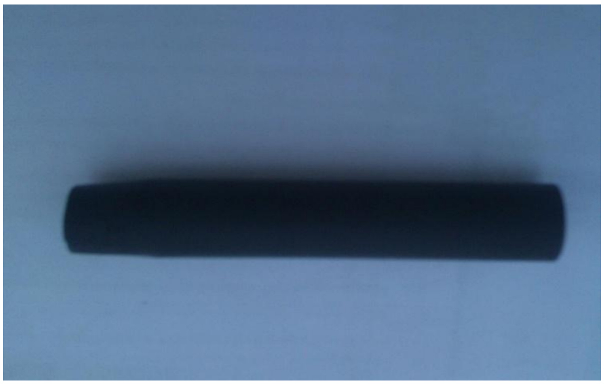

Figure 3: Graphite Electrode

Table 2: Properties of Graphite

Property	*Value*
Electrical resistivity (μ Ω/ cm)	4.9-7.5
Thermal conductivity (W/ m K)	160-210
Melting point (^{0}C)	3400
Specific gravity at 20 ^{0}C (g/ cm^3)	8.9
Coefficient of thermal expansion(*10^{-6} ^{0}C^{-1})	0.7-1.8
Density (g/ cm^3)	1.82

In this experiment we are using Graphite as electrode, which is made by powder metallurgy show in figure 3. Electro discharge machining is done on maraging steel C300 alloy. The experimental set up is show in figure 5.

Figure 4: Maraging steel C300 specimen

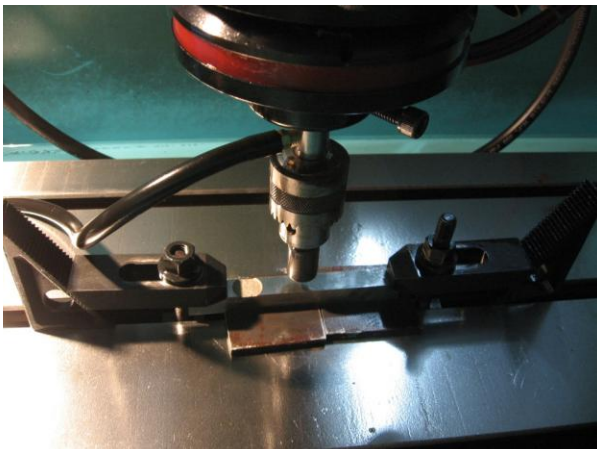

Table 5: Experimental setup for samples

After performing 9 experiments according to L9 orthogonal array using EDM, material removed rate and surface finish are measured. Material is removed in the form of crater and can be estimated for single pulse and rate at which it is given, i.e., considering the volume of a crater as part of sphere; the crater parameter can be estimated as a measure of energy.

$$MRR = \frac{1000 * \text{Weight difference}}{\text{Specific gravity* machining time}} \ mm^3/min$$

Surface finish of the work piece is calculated using talysurf equipment.

5. Taguchi Technique

Competitive changes in manufacturing in the year 1980 that gave rise to the modern quality development, leading to the introduction of Taguchi methods. Taguchi's method is a system of design engineering to increase quality. Taguchi's method refers to a assembling of fundamentals which formulate the framework of a continually evolving approach to quality. Taguchi's approach was created on popular concepts of 'design of experiments' (DOE) that is fractional and factorial designs. He created some unique DOE techniques like robust designs, signal-to-noise ratios and parameter & tolerance designs. The main objective of this robust design is to identify the controllable parameters settings for which noise has minimum effect on the product's functional characteristic i.e. not to determine uncontrollable noise parameter settings, but it for the controllable design process parameters.

5.1 Signals to Noise Ratio

By using the S/N ratio the performance characteristics due to the effect of the noise variables can be found. Where S represents the standard deviation of the performance parameters for each factor and N represents the total number of experiments. The functional variation due to the effect of the noise is denoted by the ratio. Robust design of product and the concept of S/N ratio is closely related. A Robust Design or product delivers a strong 'signal'. It execute its expected function and can cope with variations ("noise"), both internal as well as external. In signal-to-noise Ratio, the signal represents desirable value and the noise represents undesirable value.

5.2 Orthogonal Array

To reduce the total number of runs "Ronald Fisher" finds the solution called orthogonal arrays. The orthogonal array allows the designer to alter multiple variables at any time. Orthogonal array is a matrix of numbers arranged in columns & rows. Each of the columns entitled with a specific factor or condition that can be alter from every experiment. Each of the row represents the state of factors in a given experiment. The array is called orthogonal because the levels of various factors are balanced and can be separated from the effects of the other factors within the experiment.

6. Results and Discussion

In this present thesis there are two design factors and three input variables are selected. Design methodology also employed for this thesis as shown in table 3. There are many factors which are affecting the EDM process but in this thesis current, pulse on time and Pulse off time have been taken into as design factors. The main reason behind selecting the design factors is that they are the most widespread and used amongst EDM researchers. The variables selected for this study is to refer the responses of the EDM process, i.e., material removal rate & surface finish. According to the L9 Array, 9 experiments are conducted on \ work piece by using EDM machine. Table 4 shows the response of process variables on surface roughness & material removal rate on Maraging steels C300 work piece.

Table 3: Cutting parameters and their levels

Levels	Current (A)	pulse on Time (B)	Plus off Time(C)
1	10	20	19
2	15	45	36
3	20	70	53

Table 4: Effect of EDM process parameters on MRR and SR

S.N	A	B	C	MRR	SF	S/N_{MRR}	S/N_{SR}
1	10	20	19	12.9541	3.92	22.248	11.865
2	10	45	36	40.8208	5.38	32.217	14.615
3	10	70	53	43.7125	7.52	32.812	17.524
4	15	20	36	17.0000	5.78	24.609	15.238
5	15	45	53	52.6958	6.42	34.435	16.150
6	15	70	19	39.5708	5.50	31.947	14.807
7	20	20	53	36.4333	6.92	31.230	16.802
8	20	45	19	29.6916	6.32	29.452	16.014
9	20	70	36	22.4250	6.88	27.014	16.751

From the table 4 it is observed that when current is kept at 15A, the pulse on times 45sec and pulse off times 53sec MRR is high that is 52.6958 mm^3/min. At10 amp current, pulse on time is 20sec and pulse off time is 19sec, Surface roughness is low i.e. smooth surface finish equal to 7.52 µm. Because, when the current is increased from 10A to 15A the metal removal rate is increased with current. This means that, when current are higher, melting starts earlier i.e. low machining initiation time. It can be attributed that metal removal rate is proportional to the product of energy and pulse frequency. Increasing the pulse current at a constant frequency increases the energy of the pulse and ultimately higher metal removal rate. The surface roughness is increased with increase in current. When the discharge current is high, the spark intensity and discharge power are more, subsequently causing a large crater depth on the surface of the work piece, which resulted in high surface roughness value.

At 10 amp current the pulse on time is 70sec and pulse off time is 53sec at that Surface roughness is 7.52 µm which are the lowest surface finish parameters. When the pulse on time increases to 70sec, the MRR is decreased that is 39.5708 µm because the metal removal rate is decreased with increase in pulse-on-time. This is because of the short pulses which cause less vaporization, where as, long pulse duration cause the plasma channel to expand. The expansion of plasma channel cause less energy density on the work piece, which is insufficient to melt and/ or vaporize the work piece material.

6.1 Data Analysis

In this thesis the total analysis is based on Taguchi method by using MINI TAB 2017 software (in that DOE is used) the main effects are found by using input process parameter values and percentage contribution of individual effects are also found. By using ANOVA and Taguchi optimum conditions are found. From table 5 we observed that current is not showing any effect on the material removal rate. But pulse on time and pulse off time are effecting the MRR much.

Table 5: Analysis of variance test for MRR

Source	DF	Adj SS	Adj MS	F-value	P-value	Percentage contribution
current	2	71.98	35.99	0.42	0.703	2.053
pulse on time	2	564.55	282.28	3.32	0.231	43.892
pulse off time	2	592.57	296.28	3.49	0.223	35.903
Error	2	170.01	85.00			18.152
Total	8	1399.10				100.00

In this experimental work L9 orthogonal array was used. This experiment consists of three parameters and three levels as illustrated in table 3. In this Taguchi technique, all the experimental values are determined based on "larger is the better" for MRR and smaller is better for surface roughness. Then, the optimum observed values were calculated by comparing the standard analysis & analysis of variance which was based on the Taguchi method. Percentage of contribution is high for pulse on time and lower for current. P value for pulse on time is low which means it is the most effective parameter as shown in table 5.

Table 6: Response Table for Signal to Noise Ratio for MRR

Level	Current	Pulse on time	Pulse off time
1	29.09	26.03	27.88
2	30.33	32.04	27.95
3	29.23	30.59	32.83
Delta	1.24	6.01	4.94
Rank	3	1	2

Results obtained from ANOVA software, the delta value indicate difference between highest & lowest average value for each parameter. Rank 1 is given to maximum delta value that is pulse on time & rank 2 is given to the second maximum i.e. pulse off time and so on, shown in table 6 to indicate the relative effect of each factor on response. Hence pulse on time and pulse off time are mostly effect on MRR hence is given by first two ranks. Current is given by third rank hence least effect on MRR. From table 5, F value in ANOVA is used to find out if means between two populations are significantly different. Hence F value for pulse on time is maximum and for current it is minimum. Percentage of contribution indicates how much the taken parameter effect on response value.

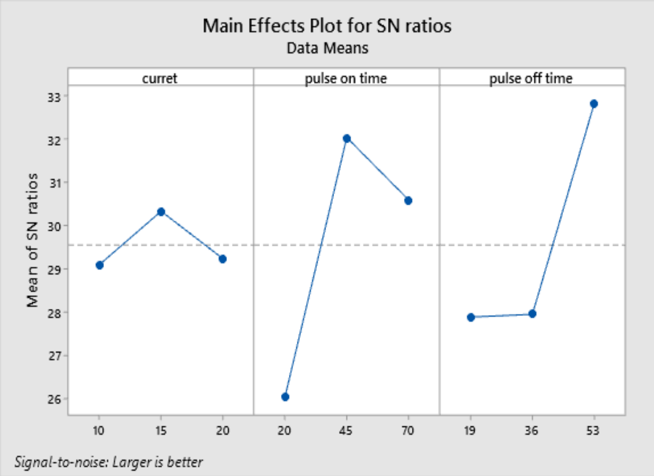

Figure: 6 Main Effective Plots for SN Ratio for MRR

From above figure 6 we can conclude that MRR first increases with pulse on time and then decreases. The maximum value of MRR obtained when pulse on time 45sec MRR is maximum. MRR is minimum when current taken as 10amp. MRR is maximum when pulse on time is 45sec and pulse off time is 53 sec.

Regression Equation for MRR

MRR = 32.81 - 0.32 curret_10 + 3.61 curret_15 - 3.29 curret_20 - 10.68 pulse on time_20 + 8.26 pulse on time_45 + 2.42 pulse on time_70 - 5.41 pulse off time_19 - 6.06 pulse off time_36 + 11.47 pulse off time_53

Table 7: Analysis of variance test for SR

Source	DF	Adj SS	Adj MS	F-value	P-value	Percentage contribution
current	2	1.947	0.9734	1.86	0.349	23.183
pulse on time	2	1.797	0.8987	1.72	0.368	19.864
pulse off time	2	4.384	2.1920	4.19	0.193	44.794
Error	2	1.045	0.5227			12.159
Total	8	9.174				100.000

Percentage of contribution is high for pulse off time ad lowest for current. It is found that pulse off time is most effective parameter as show in table 7, and hence given rank 1 in table 8.

Table: 8 Response Table for Signal to Noise Ratio for SR

Level	Current	Pulse on time	Pulse off time
1	14.67	14.64	14.23
2	15.40	15.59	15.54
3	16.52	16.36	16.83
Delta	1.85	1.73	2.60
Rank	2	3	1

Figure: 7 Main Effective Plots for SN Ratio for SR

With increase in current, pulse on time and pulse off time surface roughness increases hence optimum values should be taken i.e. current is 10 amp, pulse on time is 45sec, and pulse off time is 36sec.

Regression Equation for surface roughness

SR = 6.071 - 0.464 curret_10 - 0.171 curret_15 + 0.636 curret_20 - 0.531 pulse on time_20 - 0.031 pulse on time_45 + 0.562 pulse on time_70 - 0.824 pulse off time_19 - 0.058 pulse off time_36 + 0.882 pulse off time_53

7. Conclusions

The following conclusions were made out by this project:

1) It is evident from the results obtained that, the current have a significant effect on the Material Removal Rate (MRR) and whereas and pulse off-time have a significant effect on the Surface Roughness (Ra).
2) It is concluded that When the current 15A,T_{on} 45A and T_{off} 19sec,The MRR significantly increased and surface Roughness low.
3) It is clear that surface roughness increases with increasing the current, pulse on time and pulse off time.
4) To get good surface roughness during our investigation it was found that 3.92µm.To achieve the good surface finish, MRR will be decreased.

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