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Research Article

Experimental Study of Machining Characteristics of C 45 Steel using Electro Discharge Machining

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Abstract

Electrical Discharge Machining (EDM) is extensively used in machining of conductive materials producing intricate shapes with high accuracy. This study exhibits that EDM process parameters have a great role to obtain better material removal rate (MRR) and surface roughness (Ra). Study was conducted to investigate the effect of parameters and to optimize the parameters for the machining of C45. C-45 is a very hard material, so it is very difficult to machine these type of hard alloys by conventional machining processes. Instead of conventional machining, EDM process or non-traditional machining processes are the best machining process for the machining of hard alloys. The input parameters for the study were pulse on time, pulse current and gap voltage. The experiments were designed with the help of L9 orthogonal array. Signal to noise ratio (S/N) and analysis of variance (ANOVA) were used to analyze the effect of the parameters on MRR and SR. From the study, it has been observed that flushing pressure is significant parameter for MRR and gap voltage has a greater significance on the SR of C45.

Keywords: *EDM, C45, ANOVA etc.*

Electrical Discharge Machining

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the workpiece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Workpiece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles.

To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the workpiece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the workpiece surface. In this way several sparks occur at various locations over the entire surface of the workpiece corresponding to the workpiece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the workpiece. If the tool is held stationary, machining would stop at this stage. However if the tool is fed continuously towards the workpiece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the workpiece.

Figure Electronic EDM spark erosion 500x300

The tool and the workpiece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the workpiece is generally provided for maintaining a constant gap distance between the tool and the workpiece during machining as shown in Figure 1.1. This is performed by either a servo motor

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control or stepper motor control of the tool holder. As material gets removed from the workpiece, the tool is moved downward towards the workpiece to maintain a constant inter electrode gap. The tool and the workpiece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter electrode gap.

Principles of EDM

Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark is used as the cutting tool to cut (erode) the work piece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of High frequency current through the electrode to the work piece. This removes (erodes) very tiny Pieces of metal from the work piece at a controlled rate.

EDM process

EDM spark erosion is the same as having an electrical short that burns a small hole in a piece of metal it contacts. With the EDM process both the work piece material and the electrode material must be conductors of electricity.

The EDM process can be used in two different ways:

1. A pre shaped or formed electrode (tool), usually made from graphite or copper, is shaped to the form of the cavity it is to reproduce. The formed electrode is fed vertically down and the reverse shape of the electrode is eroded (burned) into the solid work pieces.
2. A continuous-travelling vertical-wire electrode, the diameter of a small needle or less, is controlled by the computer to follow a programmed path to erode or cut a narrow slot through the work piece to produce the required shape.

Literature review

Modi *et al*. (2015) studied that EDM process is affect by so many process parameter which are electrical and non electrical. In this project work the rotating tool is used to improve the Metal removal rate (MRR) and to observe its effect on surface finish. Taguchi's method is used as a design of experiments and response surface methodology for analysis and optimization.

Pradhan *et al*. (2014) stated that Electrical Discharge Machining performance is generally evaluated on the basis of Material Removal Rate (MRR), Tool Wear Rate (TWR), Relative Wear Ratio (RWR) and Surface Roughness (SR). The important EDM machining parameters affecting to the performance measures of the process are discharge current, pulse on time, pulse off time, arc gap, and duty cycle. A considerable amount of work has been reported by the researchers on the measurement of EDM performance on the basis of MRR, TWR, RWR, and SR for various materials.

Majumder *et al*. (2014) work deals with the prediction of optimal parametric data-set with maximum material removal rate (MRR) and a minimum electrode wear ratio (EWR) during Electrical discharge machining (EDM) of AISI 316LN Stainless Steel. For this purpose, empirical models showing relation between inputs and outputs were developed using response surface methodology. Desirability-based multi-objective particle swarm optimization-original, desirability-based multi-objective particle swarm optimization-inertia weight, and desirability-based multi-objective particle swarm optimization-constriction factor are then used to estimate the optimal process parameters for maximum MRR and minimum EWR. The results obtained by applying these three desirability-based multi-objective particle swarm optimization (DMPSO) algorithms are compared. From the comparison and confirmatory experiment, it can be observed that DMPSO-CF is the most efficient algorithm for the optimization of EDM parameters.

Singh *et al*. (2013) studied the influence of operating parameters like pulse-on-time and pulse-off-time for responses such as Metal Removal Rate (MRR) and Tool Wear Ratio (TWR) on the EDM using steel as work piece and cryogenic and non-cryogenic electrode of copper material. The cryogenic treatment is used for increasing the material removal rate and lowering the tool wear rate. It was found that with increase in pulse on time tool wear rate is decreased in both electrode cryogenic treated and non-cryogenic copper electrode. Tool wear rate is increased with increase in pulse off time. Material removal rate is decreased with increased in pulse on time from 50 μs to 100 μs and Material removal rate is increased with increased in pulse off time from 15 μs to 20 μs.

Problem formulation

From the literature view it has been observed that lot of work is reported on Electro-discharge machining of different metals using different parameters but, very little work has been reported on C-45 steel using these input parameters i.e. pulse on time, pulse current and gap voltage with Copper tool electrode in EDM. In this research work, attempt has been made to study the effect of parameters on the machining characteristics of C45 steel using Taguchi method and ANNOVA to analyze the Material Removal Rate (MRR) and Surface Roughness (SR). Table 3.1 shows the input and output parameters.

C-45 is a very hard material, so it is very difficult to machine these type of hard alloys by conventional machining processes. Instead of conventional machining, EDM process or non-traditional machining processes are the best machining process for the machining of hard alloys.

Table Input and Output parameters

Input Parameters	Output Parameters
Pulse on time	Material Removal Rate
Pulse current	Surface Roughness
Gap voltage	

Objective of present work

1) To study and optimize the EDM process parameters (Pulse on time, pulse current and Gap voltage) for the machining of C-45 Steel.
2) To understand the significance of EDM process parameters on the MRR and surface roughness of the machined metal.

Experimental set up

The EDM experiments were conducted in Sparkonix machine using copper as the tool electrode. The input parameters were Pulse Current (A), Pulse–on–time T_{on}(μs), and Gap Voltage(V). The output measures being the surface roughness of the machined surface of work material (Ra). Values of the controllable factors were chosen based on the literature review

Assumptions of experimentations

1. Throughout the experimentation input power supply is constant.
2. The vertical travel of ram of the machine is straight.
3. Fluctuation in the input current supply is neglected.
4. Spindle run out is zero.
5. Throughout the experimentation uniform flushing pressure and electrode rotation is applied.
6. Effects of variation of environmental effects are not considered.
7. Setting of work piece and electrode is same for all experiments.

Table Work piece detail

Work piece material	C-45
Length of work piece	65mm
Thickness of work piece	10mm
Width of work piece	25mm
EDM used	Sparkonix MOS 35 A
Tool Material	Copper
Vice used	70x70x30
Depth of throat	250
Environment	Wet
Dielectric Fluid	Kerosene oil

Based on the literature review and machine control levels of input factors are finalized. These levels of input parameters and General Linear model for Surface roughness $R_a$are as per following table.

Table Levels of input control factors with units

Factors	EDM Machining Parameters	Levels			Observed Values
		L1	L2	L3	
A	Pulse Current (Ampere)	10	22	32	Material Removal Rate (mm^3/min) Surface Roughness (R_a)
B	Pulse -on time (μs)	40	55	70	
C	Gap Voltage (volts)	35	55	75	

Taguchi method

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. The Taguchi method is best used when there is an intermediate number of a variable (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

Taguchi Design of Experiments in Minitab 16

MINITAB 16provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB 16 calculates response tables and generates main effects and interaction plots for:

a) Signal-to-noise ratios (S/N ratios) vs. the control factors.
b) Means (static design) vs. the control factors

Table Design of Experiment Table

Experiment No.	Pulse Current(A)	Ton (μs)	Gap Voltage (v)
1	-1	0	1
2	-1	1	2
3	-1	2	3
4	0	0	2
5	0	1	3
6	0	2	1
7	1	0	3
8	1	1	1
9	1	2	2

Table Taguchi's L9 orthogonal array with values of levels

Experiment No.	Pulse Current(A)	Ton (µs)	Gap Voltage (v)
1	10	40	35
2	10	55	55
3	10	70	75
4	22	40	55
5	22	55	75
6	22	70	35
7	32	40	75
8	32	55	35
9	32	70	55

Results and discussion

Analysis of Variance (ANOVA)

Genichi Taguchi, a Japanese engineer, proposed several approaches to experimental designs that are sometimes called Taguchi Methods. These methods utilize two-, three-, and mixed-level fractional factorial designs. Large screening designs seem to be particularly favored by Taguchi adherents.

Taguchi refers to experimental design as off-line quality control because it is a method of ensuring good performance in the design stage of products or processes. Some experimental designs, however, such as when used in evolutionary operation, can be used on-line while the process is running.

Analysis of material removal rate

Experiments were conducted using L9 Orthogonal Array shown in Table to find the effect of process parameters on the MRR. The experiments were done on C-45 Steel. The rate of cutting speed for each work piece and tool materials were collected in same experimental conditions. After performing experiment MRR value is recorded in each experiment shown in Table

Table L9 Orthogonal Array with Performance

Exp No.	Pulse Current (A)	Ton (µs)	Gap Voltage (V)	Average MRR mm³/min	S/N Ratio
1	10	40	35	4.432	12.9320
2	10	55	55	5.250	14.4032
3	10	70	75	4.259	12.5862
4	22	40	55	7.452	17.4455
5	22	55	75	6.752	16.5886
6	22	70	35	5.108	14.1650
7	32	40	75	6.889	16.7631
8	32	55	35	4.670	13.3863
9	32	70	55	5.634	15.0163

The analysis of signal-to-noise (S/N) ratio and ANOVA were carried out to study the relative influence of the machining parameters on the MRR of the Wire cut EDM machined material. Based on S/N ratio and ANOVA analysis, the optimal setting of the machining parameters for machined Material removal rate was obtained. Table 5.2 shows the analysis of variance for the MRR

Table Analysis of variance (ANOVA) for S/N Ratio w.r.t MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pulse Current	2	4.8793	4.8793	2.4396	39.04	0.025
T_{on}	2	2.3816	2.3816	1.1908	19.05	0.050
Gap Voltage	2	3.4256	3.4256	107128	27.41	0.035
Error	2	0.1250	0.1250	0.0625		
Total	8	10.8114				

The table 5.3 includes ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistic is the highest average minus the lowest average for each factor. Minitab assigns ranks based on delta values in descending order; the highest delta value has rank. 1 and rank 2 is assigned to the second highest, and so on. The ranks indicate the relative importance of each factor to the response.

Table Response Table for Signal to Noise Ratio Larger is better

Level	Pulse Current	Ton (µs)	Gap Voltage
1	13.31	15.71	13.49
2	16.07	14.79	15.62
3	15.06	13.92	15.31
Delta	2.76	1.79	2.13
Rank	1	3	2

Analysis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio will be determined to know the level of importance of the machining parameters. To obtain the optimal machining performance the higher the better quality characteristics for MRR.As can be seen from Table (above), the MRR is most significantly influenced by the Pulse Current followed by 1the Gap Voltage. The respective values of these parameters are 2.76 and 2.13. After finding all the observation as given in Table 2 & 3, S/N ratio are calculated and graph for analysis is drawn by using Minitab 16 software. The S/N ratio for MRR is calculated on Minitab 16 Software using Taguchi Method.

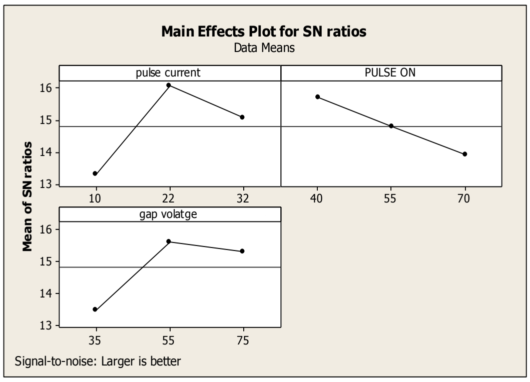

Fig S/N Ratio for MRR

Table L9 Orthogonal Array with Performance

Exp No.	Pulse Current(A)	Ton (µs)	Gap Voltage(V)	R_{a1}	R_{a2}	R_{a3}	Average R_a (µm)	S/N Ratio
1	10	40	35	4.783	3.985	4,272	4.3475	-12.7648
2	10	55	55	3.986	4.852	5.304	4.7140	-13.4678
3	10	70	75	5.814	4.638	6.222	5.5580	-14.8984
4	22	40	55	3.081	4.231	2.483	3.4800	-10.8316
5	22	55	75	4.181	5.826	5.863	5.2900	-14.4691
6	22	70	35	5.882	4.945	6.237	5.6880	-15.0992
7	32	40	75	4.786	4.011	3.552	3.4496	-10.7554
8	32	55	35	4.910	3.943	3.954	4.2690	-12.6065
9	32	70	55	4.549	3.034	3.307	3.6300	-11.1981

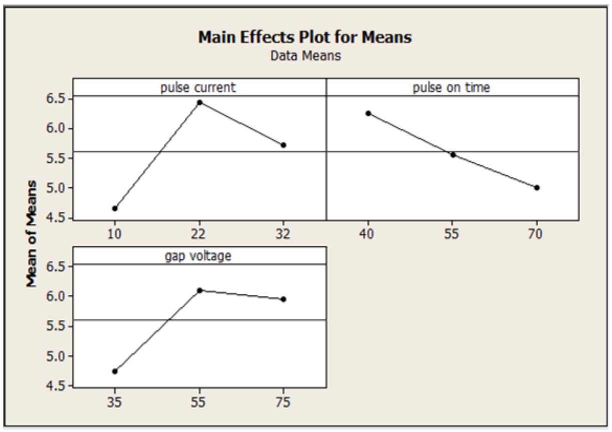

Fig Means for MRR

Analysis of surface roughness

Experiments were conducted using L9 Orthogonal Array to find the effect of process parameters on the SR. The experiments were done on C-45 Steel. The rate of cutting speed for each work piece and tool materials were collected in same experimental conditions. After performing experiment Ra value is recorded in each experiment.

Table Analysis of variance (ANOVA) for S/N Ratio w.r.t Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pulse Current	2	2.2659	2.2659	1.1330	31.90	0.030
T_{on}	2	2.4768	2.4768	1.2384	34.87	0.028
Gap Voltage	2	1.3635	1.3635	0.6818	19.19	0.050
Error	2	0.0710	0.0710	0.0355		
Total	8	6.1773				

The Table 5.6 includes ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistic is the highest average minus the lowest average for each factor. Minitab assigns ranks based on delta values in descending order; the highest delta value has rank. 1 and rank 2 is assigned to the second highest, and so on. The ranks indicate the relative importance of each factor to the response.

Table Response Table for Signal to Noise Ratio Smaller is better

Level	Pulse Current	T_{on}	Gap Voltage
1	-13.71	-11.45	-13.49
2	-13.47	-13.51	-11.63
3	-11.52	-13.73	-13.37
Delta	2.19	2.28	1.66
Rank	2	3	1

Analysis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio will be determined to know the level of importance of the machining parameters. To obtain the optimal machining performance the smaller the better quality characteristics for SR.As can be seen from Table (above), the SR is most significantly influenced by the Gap voltage followed by the Pulse Current. The respective values of these parameters are 1.66 and 2.19. After finding all the observation as given in Table 4 & 5, S/N ratio are calculated and graph for analysis is drawn by using Minitab 16 software. The S/N ratio for SR is calculated on Minitab 16 Software using Taguchi Method.

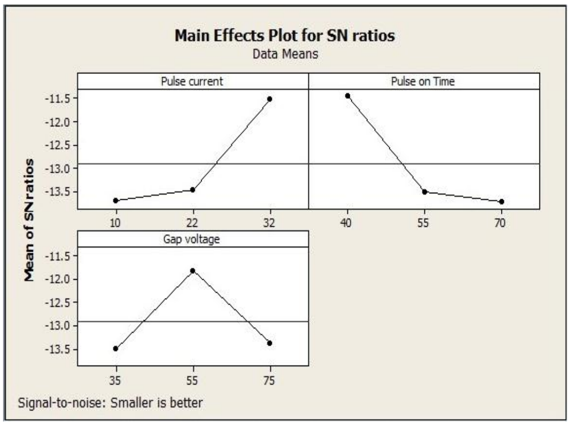

Fig S/N ratio for Surface Roughness

All the three parameters have their own effects on the Material Removal Rate and the Surface Roughness. If the current is low the material would not be removed as per desired and will take more time to cut but will give good surface roughness and when the current is more, it will remove material faster and produce low surface roughness.

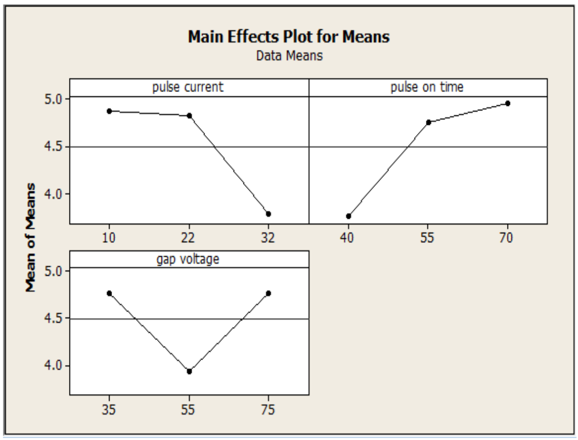

Fig Means for SR

The effect of varying current on Material removal rate is shown in Fig 5.1 It shows that the MRR first increase with the increase of current and then decreases. The effect of varying current on surface roughness is shown in Fig 5.3 and it shows that the SR first decreases with the increase of current and then increases. Pulse on time plays an important role in the machining process. It is impossible to do any machining without the Pulse on time. The machining performances during roughing cuts have been improved since the removed particles in the machining gap are evacuated more efficiently. It shows that MRR and SR escalates with the increase of current. Gap voltage specifies the supply voltage to be placed on the gap between the electrode and workpiece. The effect of gap voltage on MRR and SR are shown in Fig 5.1 and Fig 5.3 show that the MRR and SR first decrease with the increase of gap voltage and the increases. Thus an optimum value of these parameters is needed to get the maximum removal rate and good surface roughness. In this experiment the parameters for optimal removal rate are pulse current (22 ampere), pulse on time (40), and gap voltage (55 volts), for optimal surface roughness are pulse current (32 ampere), pulse on time (40), and gap voltage (55 volts).

Conclusion & future scope

From the experimental results, S/N ratio and ANOVA analysis and predicted optimum machining parameters, the following conclusions are drawn:

1) Gap Voltage has a greater influence on the surface Roughness followed by Pulse Current. Pulse on Time had the least influence on Roughness.
2) Pulse Current is the most significant parameter for Material Removal Rate, followed by Gap Voltage and Pulse Current respectively.
3) The optimum parameters for Surface Roughness are Pulse Current (32A), Pulse on Time (40µs) and Gap Voltage (55V) where, S.R 3.3314µm is obtained.
4) The ideal parameters for material removal rate are Pulse Current (22A), Pulse on Time (40µs), and Gap Voltage (55V) that results in MMR. Value of material removal rate is 7.452 mm^3/min.

Future scope

1) Study can be extended by optimizing process parameters for different materials like C-k45, D2 steel, D-3 steel, En-8, En-9, Ti-6AI-4V, etc.
2) Different parameters (TWR (tool wear ratio), dimensional accuracy, flushing pressure etc.) of the process can be examined for the machining of C-45 steel.
3) Continuation of study can take place employing some other electrodes (Brass, Copper Tungsten, Graphite, Molybdenum, Silver Tungsten, Tellirium Copper) and wear rate of tool can also be determined.

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