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Process Parameter Optimization of Die Sinking EDM: A Review

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Abstract - *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. Several approaches are proposed in the literature to solve the problems related with optimization of these parameters. It is felt that a review of the various approaches developed would help to compare their main features and their relative advantages or limitations to allow choose the most suitable approach for a particular application and also throw light on aspects that needs further attention. In view of above, this paper presents a review of development done in the optimization of EDM related process parameters.*

Key Words: MRR, TWR, RWR, SR, Die Sinking EDM.

1. INTRODUCTION

Electrical Discharge Machining (EDM) is an important manufacturing process for machining hard metals and alloys [2]. This process is widely used for producing dies, molds, and finishing parts for aerospace, automotive, and surgical components [3]. The process is capable of getting required dimensional accuracy and surface finish by controlling the process parameters [4]. EDM performance is generally evaluated on the basis of Material Removal Rate (MRR), Tool Wear Rate (TWR), Relative Wear Ratio (RWR), and Surface Roughness (SR) [3].

The important EDM parameters affecting to the performance measures of the process are discharge current, pulse on time, pulse off time, arc gap, and duty cycle [9].In EDM, for optimum machining performance measures, it is an important task to select proper combination of machining parameters [13]. Generally, the machining parameters are selected on the basis of operator's experience or data provided by the EDM manufactures. When such information is used during Electrical Discharge Machining, the machining performance is not consistent. Data provided by the manufacturers regarding the parameter settings is useful only for most commonly used steels. Such data is not available for special materials like Maraging steels, ceramics, and composites. For these materials, experimental optimization of performance measures is essential. Optimization of EDM process parameters becomes difficult due to more number of machining variables and slight changes in a single parameter significantly affect the process.

Thus, it is essential to understand the influence of various factors on EDM process. Analytical and statistical methods are used to select best combination of process parameters for an optimum machining performance. Different author use different combination of process parameters. They analyze the experimental data by plotting Interaction graphs, Residual plots for accuracy and Response curves. Some other methods used by different author for analysis of Taguchi's DOE data related to Electrical Discharge Machining (EDM) and Wire Electrical Discharge Machining (WEDM) are Regression analysis, Response Surface Methodology, Central Composite Design (CCD), Feasible-Direction Algorithm, SA algorithm, Pareto, Artificial Bee Colony (ABC), Grey Relational Analysis, Genetic Algorithm, Fuzzy clustering, Artificial Neural Network, Tabu-Search Algorithm, Principle component method etc.

Most of the author used L_9 Orthogonal Array. Generally the effect of Pulse ON time, Pulse OFF time, Spark gap set Voltage, Peak current, Flushing Pressure, Work piece height, wire tension and wire feed on the material removal rate, surface roughness, kerf and gap current is investigated.

2 VARIOUS MATHODS USED IN OPTIMIZATION OF EDM PROCESS PARAMETERS

The studies used various techniques for optimization of process parameters can be broadly classified into two categories namely classical or numerical techniques and modern techniques. After analysing the detailed literature review the major optimization techniques and tools utilized by various researchers are as follow:

Multi-response optimization, artificial neural network, grey entropy, Taguchi Technique, Back Propagation Neural Network, Fuzzy Logic, Linear Regression Technique, Grey-Taguchi Method, simulated annealing, Multi-Objective Genetic Algorithm, Feasible-Direction Algorithm, SA algorithm, Pareto, Artificial Bee Colony (ABC), Tabu-Search Algorithm, Principle component method, Trust region method.

2.1 Input process parameters

Work Piece Material, Percentage Composition, Electrode Material, Peak Current, Discharge Current, Pulse on time, Pulse off time, Cutting Speed, Dielectric flushing pressure, Arc Gap, Duty Cycle, Taper Angle, Tool Shapes, Tool Area, Voltage, Rotational Speed of Electrode, Feed Rate, Pulse Frequency, Wire Speed, Wire Tension, Dielectric Flow Rate, Spark Gap Voltage, Axial–radial depth of cut, Machining Tolerance.

2.2 Process performance

Material Removal Rate (MRR), Tool Wear Rate (TWR), Relative Wear Ratio (RWR), and Surface Roughness (SR), kerf (width of cut), Dimensional deviations, Stability factor (S_f).

2.3 Electrode performance

The material used for electrode can be copper, brass, tungsten, graphite, steel, Copper–tungsten, copper– chromium alloy, haste alloy, molybdenum, chromium coated copper alloy, Brass-CuZn37, coated ceramic tool, Al–Cu–Si–TiC P/M composite material, Al-10%SiCp composites etc.

2.4 Workpiece material

The materials investigated on WEDM generally of HSS and other Tool materials are Hot Die material, Cold Die material, Nickel alloys and Titanium alloys which are hard compare to other material. These materials are AISI M2, AISI D2, AISI D3, AISI D5, AISI H11, AISI 4140, SKD 11, En 16, En 19, En 31, En 32, 1040, 2379, 2738, Inconel, Ti alloys, Al alloys, 7131 cemented, Tungsten Carbide (WC) , Al 7075-B_4C MMC, Titanium (grade-2), CK45 steel, EN-31 die steel, Inconel-600, High strength low alloy steel (HSLA), D2 tool steel (1.5%C, 12% Cr, 0.6%V, 1% Mo, 0.6% Si, 0.6% Mn and balance Fe), Al-SIC (20%), stainless steel AISI 304, medium carb on steel (EN8), Maraging steel (MDN 300), WPS DIN 1.2379/AISI D2 tool steel, AISI A2 tool steel, Maraging steel (MDN 250), WPS DIN 1.2379 tool steel, γ-TiAl, cryogenic-treated D-3 steel, SKD 61 steel, copper–steel (EN-8), Al2O3/6061Al composite etc.

3 EXISTING RESEARCH WORK

Puri et. al. [1] employed mathematical modeling of white layer depth to correlate the dominant input parameters of the WEDM process, comprising of a rough cut followed by a trim cut In the process, typical die steel (M2 – hardened and annealed) was machined using brass wire as electrode. An experimental plan of rotatable central composite design in RSM consisting of input variable pulse on time during the rough cutting and pulse on time offset and cutting speed during trim cutting has been employed to carry out the experimental study and concluded that the white layer depth increases with increasing pulse on time during the first cut and decreases with increasing pulse on time during trim cutting. With increasing cutting speed in trim cutting, the white layer depth first reduces and then starts increasing.

T. A. El-Taweel [2] investigated the relationship of process parameters in EDM of CK-45 steel with novel tool electrode material such as Al-Cu-Si-TiC composite product using powder metallurgy technique. In this study, peak current, dielectric flushing pressure and pulse on time are considered as input process parameters and the process performances such as MRR and TWR were evaluated. The analysis was carried out with the help of response surface methodology. It was concluded that the peak current was found to be the most important factor effecting both the MRR and TWR while dielectric flushing pressure has little effect on both responses. Al-Cu-Si-Tic electrodes were found to be more sensitive to peak current and pulse on time than conventional electrodes.

Sohani et. al. [3] presented the application of response surface methodology (RSM) for investigating the effect of tool shapes such as triangular, square, rectangular and circular with size factor consideration along with other process parameters like discharge current, pulse on time, pulse off time and tool area. The investigation revealed that the best tool shape for higher MRR and lower TWR is circular, followed by triangular, rectangular and square cross-sections. From the parametric analysis, it was also observed that the interaction effect of discharge current and pulse on time is highly significant on MRR and TWR, whereas the main factors such as pulse off time and tool area are statistically significant on MRR and TWR. The ANOVA was employed along with Fisher's test (F test) at 95% confidence interval to verify the lack of fit and adequacy of developed model.

Asif Iqbalet. al.[4] established empirical relations regarding machining parameters and the responses in analyzing the machinability of the stainless steel AISI 304 using copper electrode. The machining factors used were voltage, rotational speed of electrode and feed rate over the responses MRR, EWR and SR. The response surface methodology was used to investigate the relationships and parametric interactions between the three control variables on the MRR, EWR and SR. the developed models show that the voltage and rotary motion of electrode are the most significant machining parameters influencing MRR, EWR and SR.

Nanimina et. al. [5] studied the effects of EDM on Al6061- 30%Al2 O3 .Metal matrix composites. They selected peak current, pulse on time and pulse off time as machining parameter and material removal rate and tool wear rate as responses. They found the High current and pulse on time increase the material removal rate. More tool wears are observed at low peak current and pulse on time.

Anish et. al. [6] developed quadratic models for the machining rate, surface roughness and dimensional deviation to correlate the dominant machining parameters: pulse on time, pulse off time, peak current, spark gap voltage, wire feed & tension in wire EDM process for pure titanium. An experimental plan of the Box-Behnken based on RSM has been applied to perform the experimentation work and determined that the most significant parameters with respect to the response variables are found to be pulse on time, pulse off time, peak current & spark gap voltage and also conclude that the machining rate, surface roughness and dimensional deviations were fairly well fitted with the experimental results with 95% confidence level.

Raj Mohan et. al. [7] investigated the influence of process parameters and their interactions viz., voltage, pulse on time, current and pulse off time on the material removal rate (MRR) in stainless steel (304) as workpiece. Signal to noise ratio (S/N) and analysis of variance (ANOVA) was used to analyze the effect of the parameters on MRR and Taguchi method used to find the optimum cutting parameters. It was concluded that the two main significant factors that affects the MRR are pulse current and pulse on time.

Herpreet Singh et. al. [8] 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 workpice 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 50μs to 100μs and Material removal rate is increased with increased in pulse off time from 15μs to 20μs.

Nikalje et. al. [9] studied the influence of process parameters such as discharge current, pulse-on-time and pulse-off-time for process performance criteria such as MRR, Tool Wear Ratio (TWR), Relative Wear Ratio (RWR) and surface roughness. The MDN 300 steel was used as workpiece material and copper as electrode. The Taguchi method was employed for optimization. It was found that the optimal levels of the factors for SR and TWR are same but differs from the optimum levels of the factors for MRR and RWR. From ANOVA, discharge current is more significant than pulse on time for MRR and TWR; whereas pulse on time is more significant than discharge current for RWR and SR. on the other hand, pulse off time is less significant for all performance characteristics considered.

Manabhanjan Sahooet. al. [10] studied the influence of process parameters such as discharge current, pulse-on-time and duty cycle for process performance criteria such as metal removal rate (MRR) and electrode wear rate (EWR). Experiments are conducted on tungsten carbide with copper electrode in a die sinking EDM. Response Surface Methodology had been employed to develop mathematical model and to establish empirical relationships between process parameters and process responses. It was found that the peak current was found to be the most important factor effecting both the MRR and EWR. It had been found that the Maximum MRR was achieved at 10 A discharges current, 50μs pulse on time and 8 duty cycle and minimum EWR was achieved at 6 A discharge current, 10μs pulse on time and 8 duty cycle.

Md. Khajaet. al. [11] considered the effects of various machining parameters on machined surface roughness. In the process, typical die steel (K 100 grade) was machined using brass wire as electrode. Pulse on time, pulse off time, wire feed rate, wire tension, spark gap set voltage and peak current were the machining parameters chosen to conduct the experiment. After analyzing the effect of each relevant factor on surface roughness, appropriate values of all parameters are chosen and a fine surface of roughness equals to 0.22 μm is achieved. It was concluded that pulse on time and pulse off time were significant variables to the surface roughness. It was noticed that excellent machined surface quality could be obtained by setting machining parameters at a low pulse current and short pulse on time. But this combination will unfortunately produce low material removal rate and cause high machining time.

Rengasamy et. al. [12] engineered metal matrix composites (MMC) in which aluminium 4032 is reinforced with reinforcement particles Zrb_2 and Tib_2 in various Wt. % (0,2,4,6,8) at room temperature through the stir casting method. Machining is carried out with copper electrode where input parameters were pulse on time, pulse off time and current. To find the optimize process parameters the Taguchi L_{25} orthogonal array is used. The analysis of variance (ANOVA) was used to investigate the percentage of contribution by each parameter. The most influencing process parameter in obtaining minimum material removal rate, tool wear rate and depth are obtained value about 0.190 (g/min), 0.005 (g/min) and 2.155 (g/min) from the input parameter value of about 8 Wt. % composites, pulse on time, pulse off time, current of about 7.0 (μs), 7 (μs), 26 (Amps) respectively.

Selvarajan et. al. [13] investigated the machining of Si_3N_4-TiN ceramic composite using a copper electrode as a EDM tool. The machining parameters, such as the current, pulse on time, pulse off time, dielectric pressure and spark gap and servo voltage were investigated using a Taguchi L_{25} orthogonal array. The output parameters such as material removal rate, tool wear rate, wear ratio, surface roughness, top radial over cut, bottom radial over cut, taper angle, circularity, cylindricity, perpendicularity, and run out were examined during the sparking operation. The significance of the machining parameters was obtained using analysis of variance (ANOVA) based on grey relational analysis (GRA), which showed that the current pulse on time and spark gap voltage were the most significant parameters.

Verma et. al. [14] studied the effect of EDM of process parameters on titanium alloy. For this purpose die-sinking EDM was used and for optimization full factorial technique was used. The input parameters were peak current, gap voltage, pulse on time and dielectric fluid pressure. Material removal rate and surface roughness were taken as response parameters. It was found that the dominant parameters for MRR and SR is peak current followed by gap voltage, pulse on time and fluid pressure. Their percentage contribution in case of material removal rate are 64.08%, 6.32%, 20.46% and 5.60% respectively and in case of surface roughness 70.78% , 10.63%, 6.92% and 6.35% respectively.

Bhosle et. al. [15] applied grey relational analysis and found a unique optimal parameter setting for micro-electrical discharge machining in drilling process of inconel 600 alloy. For this, the five effective process parameters such as voltage, capacitance, EDM feed rate, pulse-on time and pulse-off time are varied and micro holes were drilled using tungsten carbide tool. The material removal rate, taper angle, overcut and diameteral variance at entry and exit of a micro hole were the measured performance characteristics. Analysis of variance (ANOVA) was performed to understand the effects, contributions and significance of the process parameters. Taguchi method was used to design L_{18} orthogonal array, the optimal machining performance for maximum material removal rate and minimum taper, overcut and diameteral variation were obtained for 175V voltage, 1000 pF capacitance, 20 μm/s EDM federate, 15 μs pulse duration and 50 μs pulse interval..

Chandramouli et. al. [16] studied the effect of EDM process parameters on machining of 17-4 PH steel. Parameters that have been selected are peak current, pulse on time, pulse off time and tool lift time and output response are material removal rate (MRR) and surface roughness (SR). Taguchi method was used to design L_{27} array with copper tungsten electrode. ANOVA method was used with the help of MINITAB 17 software to analysis the influent of input process parameters on output response. The result of ANOVA reveals that pulse on time has highest percentage contribution for MRR (58.3%) and for SR (76.7%).

Koteswararao et. al. [17] studied the effect of machining parameters on EN 31 high carbon steel alloy. The signal to noise ratio associated with the observed values in experiments were determined to find which factor is most affected by the responses of material removal rate (MRR), tool wear rate (TWR) and over cut (OC). Discharge current is most influencing factor on MRR and then pulse duration time and the last is diameter of the tool. MRR increased with I. As pulse duration extended, MRR decrease monotonically. In the case of TWR the most important factor is I the pulse on time and after that D. In the case of OC the most important factor is I and then D and no effect on pulse on time.

Maradia et. al. [18] optimized the EDM drilling process for hard to machine materials and for this work stochastic optimization algorithm is used. The robustness of the algorithm is evaluated for different EDM drilling process disturbances, such as electrode shape and electrode length. The performance of the optimization algorithm is further evaluated in terms of effect of initial parameters and number of iterations required to converge to optimal values for highest material removal rate. It was found that the optimization algorithm is able to reach the optimal values after about 40 iterations, where the achieved MRR is at least 10% higher then the MRR obtained by using the high speed strategy from the standard machine technology.

The specific analysis performed in the different areas as discussed by this review paper

Table -1: The specific analysis is performed in the different areas as discussed by this review paper

Name of Researcher	Year	Contribution	Workpiece material	Electrode material	Parameters	
					Input	Response
Puri et. al.	2003	Investigation of white layer depth in a wire cut EDM process through methodology	Die steel	Brass	Pulse on time	Cutting speed, White layer depth
T.A. El-Taweel et.al.	2008	Investigated the multi response optimization of EDM with AL-Cu-Si-Tic P/M Composite Electrode	C k 45 Steel	Al-Cu-Si-TiC P/M Composite	Peak current, dielectric, flushing pressure, pulse on time	MRR, TWR
Sohani et.al.	2009	Investigated into the effect of tool shape with size factor consideration in sink electrical discharge machining (EDM) process			Discharge current, pulse on time, pulse off time, tool area	MRR, TWR
Asifiqbal et.al.	2010	Investigated modeling and analysis of MRR, EWR and surface roughness in EDM milling through RSM	Stainless steel (AISI 304)	Copper	Voltage, Rotational Speed, Feed rate	MRR, EWR, SR
Nanimina et.al.	2010	Effect of EDM on aluminium metal matrix composite	Aluminium metal matrix composite (Al-6061)		Peak current, pulse on time, pulse off time	MRR, TWR
Anish et.al.	2012	Prediction of surface roughness in wire electrical discharge machining process based on response surface methodology	Pure Titanium	Copper	Pulse on time, Pulse off time, Peak current, Spark gap, Voltage, Wire feed, Wire tension	SR
Raj mohan et.al.	2012	Optimization of machining parameters in EDM of (304) stainless steel	Stainless steel - 304		Pulse off time, pulse on time, voltage	MRR
Harpreetsingh et.al.	2013	Effect of pulse on time and pulse off time on machining of steel using cryogenic treated copper electrode	Steel	Copper	Pulse on time, pulse off time	MRR, TWR
Nikalje et.al.	2013	Influence of parameters and optimization of EDM	MDN 300 steel	Copper	Discharge current, pulse on time,	MRR, TWR, RWR

		performance measure on MDN 300 steel using Taguchi method			pulse off time	
Manabhanjan et.al.	2013	Experimental investigation of machining of tungsten carbide by EDM and its mathematical expression	Tungsten carbide	Copper	Discharge current, pulse on time, duty cycle	MRR, EWR
Md. Khaja et.al.	2013	Effects of machining parameters on surface finish over hardened die steel working on wire EDM machine	Die steel (K 100 grade)	Brass	Pulse on time, pulse off time, wire feed rate, wire tension, spark gap, voltage peak current	SR
Rengasamy et.al.	2016	Analysis of mechanical properties and optimization of EDM process parameters of Al 4032 alloy reinforced with Zrb_2 and Tib_2 in-situ	Al 4032	Copper	Pulse on time, pulse off time, current	MRR, TWR and Depth
Selvarajanet.al.	2016	Optimization of EDM process parameters in machining Si_3N_4-TiN conductive ceramic composite	Si_3N_4-TiN	Copper	Current, pulse on time, pulse off time and dielectric pressure and spark gap voltage	MRR, TWR, wear ratio, surface roughness, top radial over cut, bottom radial over cut, taper angle, circularity, cylindricity, perpendicularity and run out
Vermaet.al.	2017	Optimization of die sinking EDM on titanium grade-V alloy (Ti6Al4V) using full factorial design approach	Titanium grade – V alloy (Ti6Al4V)	Copper	Peak current, gap voltage, pulse on time and dielectric fluid pressure	MRR, SR
Bhosle et.al.	2017	Multi- performance optimization of micro-EDM drilling process of inconel 600 alloy	Inconel 600	Tungsten carbide tool	Voltage, capacitance, EDM feed rate, pulse on time and pulse off time	MRR, taper angle, overcut and diameteral variance
Chandramouli et.al.	2017	Optimization of EDM process parameters in machining of 17-4 PH steel using Taguchi Method	17-4 PH steel	Copper tungsten tool	Peak current, pulse on time, pulse off time and tool lift time	MRR, SR
Koteswararao	2017	Investigated the machining	Steel – EN31	Copper	Discharge current, pulse on time and	MRR, TWR, over

et.al.		parameters in EDM of high carbon steel alloy (EN31)		tool	diameter of tool	cut
Maradia et.al.	2018	Optimisation of EDM drilling using stochastic technique	Hard materials		Electrode length and electrode shape	MRR
Buschaiah et.al.	2018	Investigated the influence of EDM parameters on machining characteristics of Aisi 304	AISI 304 steel	Copper	Current, pulse on time and electrode diameter	SR

4 CONCLUSION

The analysis of researches in the area of optimisation of EDM over past decades reveals that the performance of EDM is generally evaluated on basis of various performance parameters in which major ones was material removal rate, tool wear rate and surface roughness. The performance is affected by pulse on time, pulse off time, discharge current, duty cycle, wire feed rate, wire tension, servo voltage, rotational speed and flushing pressure. The review paper evaluates the areas and subareas where optimization techniques have been deployed. It works on identifying parameters for optimization and also suitable techniques for EDM mechanism.

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