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Optimization of Process Parameters of Electrical Discharge Machining Process For Performance Improvement

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Abstract*: *Unconventional machining methods are used where conventional techniques are unachievable, inacceptable or cost ineffective. Number of unconventional techniques has been developed to achieve special machining conditions. When these methods are engaged properly, they provide several benefits over conventional methods. High strength alloys can be machined easily, complicated contours and difficult geometries with close tolerances and better surface topograph can be developed using unconventional processes. One of the most popular unconventional machining methods is electrical discharge machining. In this paper, the detailed investigation has carried out to give an insight into the progression of research in the domain of spark machining and optimizing important process variables of this type of machining. It has been found from the available literature that optimization of process parameters of electrical discharge machining can improve machining performance pertaining to material removal and surface finish. Identifying the research gaps and are presented under the heading analysis and discussion. Conclusions drawn from this work will be useful in carrying out research in the sphere of unconventional EDM.

Keywords*: *Electrical discharge machining, unconventional machining, optimization of process parameters, material removal rate, tool wear rate.

I. INTRODUCTION

Electrical is discharge machining process is un-conventional machining method popular from almost seven decades [1]. Other names for this type of machining are spark machining and spark eroding. Process of EDM has gained popularity worldwide and substituted conventional machining methods. In this type of machining process, material expulsion utilizes electrical energy and transforms it into heat through a progression of rapidly repeating sparks amidst tool and workpiece immerged in a dielectric medium. One of the electrodes is tool while the other is work-piece. The shape of the material removed is controlled to develop an object with required geometry and surface finish. In such machining, tool and workpiece do not have immediate interaction. This process is employed to machine hard metals like titanium and pre-hardened steel and materials which can't be easily machined by means of traditional process.

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II. OBJECTIVE OF PRESENT STUDY

The main target of the present study is to analyze the available literature on optimization of EDM process parameters and present it in a systematic order so that it can be used for further research. A number of researches have been conducted on different dimensions of electrical discharge machining process. Optimization is process of achieving the best results under given conditions. There are numerous optimization methods used in EDM process. Investigations have been carried out for optimization of important process parameters of EDM and their influence on output parameters and hence, machining performance of EDM. The results of such literature review are presented in this work.

III. PRACTICAL UTILITY OF EDM

Ability of spark machining process to function solitarily for hours or days enhances its utility. By employing this process, it becomes easy to work on hard and difficult to machine materials [2]. Parts having complicated, specific and inconsistent dimensions and complex inner configuration can be easily manufactured by EDM process [3]. Composites and ceramics, which are otherwise hard to work, conceivably machined using this process. Spark erosion can be used to produce gear and internal threads [4]. It finds extensive applications in mould and die manufacturing industries [5]. It is finds application in aircraft, automobile, telecommunication and biotechnology industries [6]. Its applications can also be found in the electronics, healthcare, optics, sports, jewellery making and toys manufacturing [7].

IV. ADVANTAGES OF EDM

EDM operation offers following advantages over conventional machining methods:

1. Stock removal in spark machining is predominantly depends upon thermal characteristics of the workpiece material instead of mechanical properties [8].
2. Complicated cutting profile, pointed and briery angles and internal junctions can be easily created.
3. Machining of hardened material can be conducted without any distortion. [9]
4. Forces developed during machining operation are negligible.

5. Difficult-to-machine materials can easily be machined [10].

V. LIMITATIONS OF EDM

The limitations of EDM operation are as follows:

1. Metal expulsion rate in as case of EDM is comparatively low.
2. Overall machining operation is slower as compared to conventional methods. [7]
3. This process is applicable to electrically conductive materials only. The tool used should also be electrically conductive.
4. Sometimes the wear rate of tool is high due to which more than one tool may be required to complete the operation. [3]

VI. STUDIES ON ELECTRICAL DISCHARGE MACHINING

Due to several advantages offered by EDM process, numerous researchers worldwide have conducted investigations on machining of different materials using this process. Headways in EDM technology can be referred in several reviews by researchers.

Zhang et al. (1997) [11] suggested a model for machining ceramic. They observed that MRR, SR and diameter of discharge point increments with increase in on-time and current. Further, current was observed to have greater impact on MRR, whereas on-time has larger impact on SR and thermal affected layer. Kunieda and Yoshida (1997) [12] found that the performance of electric discharge machining process using gas (air and O_2) was more superior in comparison with a dielectric liquid under exceptional conditions i.e., utilizing a tubular electrode having wall thickness less than 0.3 mm, -ve tool polarity, tool rotation and high gas stream speed.

Zaw et al. (1999) [13] examined the utilization of compounds of ZrB_2 and TiSi having different composition of copper as electrode material in EDM process and contrasted their performance with that of traditional materials like Cu, graphite, Cu-W and rapid tool developed using selective LASER sintering machine. TiSi/Cu compound was observed to be totally beyond the satisfactory level as electrodes. ZrB_2/Cu was found to have EWR between Cu and graphite, yet the machining rate was seen to low while REWR was observed to be greater than that for traditional materials. Li et al. (2001) [14] explored influence of TiC in sintered Cu-W electrodes on electrical discharge machining operation. Electrodes having added TiC demonstrated appreciable performance. SR diminished with an increase in relative density and contrariwise. Minimal EWR, utmost MRR and supreme surface finish were acquired with 15% TiC addition. Tsai et al. (2003) [15] proposed process of mixing Cu powder contained resin with Cr powder for fabricating tools. The outcomes demonstrated that utilizing such electrodes resulted in development of changed surface layer over the workpiece after electrical discharge machining, with astounding corrosion resistant characteristics. Greater MRR was observed when contrasted with Cu electrodes. Also, Chromium present in the tool moved to the work sample, which resulted in a good corrosion resistant attributes. Ekmekci et al. (2005) [16] experimentally measured residual stresses and hardness depth on surfaces produced after electrical discharge machining. A significant increase in stresses were observed in relation to depth, achieving utmost value near the yield strength and after that decreases quickly to compressive residual stresses in the core of the material.

Guu (2005) [17] inspected the surface morphology, SR and micro-crack of AISI D2 tool steel machined using EDM. It was observed that a phenomenal machined finish was acquired at low pulse energy. Furthermore, SR and depth of the micro-cracks were relative to power supplied. Hascalik and Caydas (2007) [18] contemplated machining of Ti-6Al-4V by EDM process utilizing various tool materials. MRR, SR, electrode wear and average white layer thickness were observed to increment with increasing current density and pulse duration. In any case, incredibly long-pulse durations decrease MRR and SR. Likewise, surface hardness was found to increase. Graphite electrode was found to give better MRR, EWR and surface crack density but comparatively inferior surface finish.

Khanra et al. (2007) [19] created ZrB_2-Cu composite by including various measures of Cu and used it as tool to machine mild steel. The outcome exhibited that ZrB_2-40wt%Cu composite has more MRR and lesser TWR than conventional Cu electrode. However, lesser diametric overcut and average SR were observed with Cu electrode. Janmanee and Muttamara (2010) [20] investigated the performance of EDM using various electrodes on tungsten carbide (W90-Co10). Graphite, Cu-graphite and Cu-W were used as electrodes. It was noted that electrode negative polarity performs well. Graphite electrode gave higher MRR when contrasted with different electrodes while Cu-W electrode gave the best SR at 20 A peak current.

Beri et al. (2012) [21] examined the impact of polarity and current while machining of Inconel 718 alloy steel on EDM with Cu-W electrode. MMR was found to increase with increment in current while TWR decreased slightly. SR increased with increment in current. SR obtained with –ve polarity was observed to be altogether lower as contrasted with that got with +ve polarity. Rana and Sham (2013) [22] experimental investigated surface integrity of Co bonded tungsten carbide machined on EDM utilizing Cu-SiC composite as electrode. Process parameters were observed to have considerable affect on machining parameters. MRR was observed to increment with peak current while SR decreased. Wei et al. (2013) [23] employed ceramic matrix composite reinforced with ceramic fibers. Electrode vibration and dielectric flushing were employed for advancing material expulsion process. An increment in MRR and SR without sacrificing TWR was noted. High gap voltage or low duty ratio was observed to prompts higher machining rate. Boopathi and Sundaram (2014) [24] researched on impact of input parameters for ED machining of Inconel 718 using nano-particle included in to dielectric fluid and brass electrode. Improvement in material expulsion rate and reduction in TWR rate was noticed. Hadad et al. (2018) [25] explored affect of tool initial surface roughness on MRR, SR and TWR.

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It was noticed that the peaks and valleys prompts SR of the workpiece to reduce, while expanded TWR with lessened MRR at the expense of high voltage were observed.

VII. STUDIES ON OPTIMIZATION OF PROCESS PARAMETERS OF EDM

The primary objectives of EDM process include accomplishment of a superior stability and greater productivity. Nowadays, new intriguing materials are developed and more complicated contours are to be manufactured. Traditional methods have their constraints on the other hand use of the spark machining in manufacturing keeps on growing at a faster rate. In exceptionally competitive world nowadays, the manufactures extreme objectives are to develop a high quality item with less expense and time imperatives. In order to accomplish such objectives, one of the contemplations is by optimizing input parameters. Thus, application of optimization techniques is essentially required for improving quality of product and to sustain competitiveness in the manufacturing sector. Optimization is the technique of acquiring the best outcomes in given conditions. There are several techniques of optimization used in EDM process. Various research have been conducted for optimization of input parameters of EDM, which is an powerful option for producing very complicated design with high precision in advanced materials like material matrix composites. The result of the literature search regarding the affect of EDM process parameters on the response parameters are exhibited here.

Mohan et al. (2002) [26] evaluated the influence of electrode rotation on electrical discharge machining of Al-SiC composite. They optimized that the machining conditions namely polarity, peak current, electrode material, vol. % SiC, pulse duration and rotation of electrode for maximum MRR. It was found that increment in the vol. % of SiC has an inverse impact on MRR and positive effect on TWR and surface finish. Increment in speed of rotation of electrode showed positive impact on MRR, TWR and better SR was observed. Singh et al. (2004) [26] explored machining of Al-10%SiC_P MMC on EDM using orthogonal array with GRA for optimization of the multi-response variables. The experimentation for the optimum setting demonstrated that there was significant improvement all the while. As a result of optimization, multi-response variables were changed to a single response grey relational grade.

Kansal et al. (2006) [28] conducted optimization EDM utilizing Si powder added dielectric liquid. They additionally built up a modified powder mixed dielectric circulation mechanism for conducting experiments. Performance of powder mixed EDM improved remarkably as compared with conventional system. It was also seen that MRR increments with an addition of suitable quantity of Si powder into dielectric medium. Mandal et al. (2007) [29] modeled EDM process for MRR and EWR. They carried out seventy eight experiments on C40 steel with Cu electrode. They utilized ANN for modeling and Non-Sorting Genetic Algorithm-II (NSGA-II) for optimization. They conducted experiments over a wide range of machining conditions for testing and validation of the model. Test outcomes showed that the model is suitable for predicting the response parameters.

Kanagarajan et al. (2008) [30] investigated electrical discharge machining of tungsten carbide/cobalt cemented carbide. They studied effect of electrode rotation, on-time, current and flushing pressure on MRR and SR. Combination of low on-time and high peak current, rotational speed and flushing pressure resulted in greater MRR and lesser SR. Habib (2009) [31] examined influences of different variables of EDM process by developing a thorough mathematical model. They applied RSM technique while the ampleness of the models was tried through the ANOVA. Al-SiC composite was used as the work sample. Optimum values of process variables were obtained for accomplishing controlled EDM of the workpiece. It was found that the MRR increments with an increment in on-time, peak current and voltage while it reduces with increase in % of SiC.

Lajis et al. (2009) [32] studied electrical discharge machining of WC ceramic using graphite electrode and applied Taguchi technique. Analysis showed that peak current affects EWR and SR while pulse duration predominantly influenced MRR. Test results were used for confirmation. Pradhan and Bhattacharyya (2009) [33] examined RSM and ANN techniques with back-propagation-algorithm-based mathematical modeling. The output characteristics of µEDM were optimized during machining of micro-hole on Ti-6Al-4V. ANN model utilized a back-propagation neural network algorithm, which was prepared with response values obtained by experimentations. The Levenberg–Marquardt training algorithm was used for a multi-layer feed-forward network.

Chen et al. (2010) [34] optimized parameters of EDM for machining ZrO_2 ceramic using Taguchi technique. ANOVA technique was used to analyze the parameters influencing EDM performance. It was noted that peak current and pulse duration greatly influenced MRR and SR. Adhesive conductive material were the noteworthy parameter related with EWR. Nejad (2011) [35] optimized machining parameters of EDM while machining SiC. He employed neural network and non-dominating sorting genetic algorithm. Eighty one experiments were carried out with various machining parameters for maximum MRR and minimum SR. Test outcome showed that that the presented model is suitable for predicting the response parameters.

Pradhan and Das (2011) [36] utilized recurrent neural network for predicting MRR values during machining of AISI D2 tool steel on EDM. This model was validated using set of experimental data. It was found that proposed model can foresee MRR acceptably with average error less than 6%. They observed that that MRR increased with increments in pulse duration, current and duty cycle. Gopalakannan et al. (2012) [37] explored the influence of input parameters on Al 7075-B_4C nano-composite. MMNC was machined on EDM using Cu electrode by adopting face-centred central composite design of RSM. ANOVA technique was applied to examine the impact of input variables. Chief factors that influence MRR were found to be pulse current and on-time.

Rajmohan et al. (2012) [38] examined impact EDM input variables on stainless steel 304. They conducted various test according to design of experiments approach of L_9 orthogonal array.

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ANOVA technique and response graphs were used to analyze results. They observed that current and pulse off-time to be the noteworthy variables for MRR. Singh (2012) [39] optimized various input parameters for EDM operation of 6061Al/Al2O3p/20P aluminium MMC. They found that pulse current was found to have strongest impact among various process parameters. It was found that through grey relational analysis, the optimization of the various variables can be simplified to a great extent.

Gopalakannan et al. (2013) [40] conducted experiments on Al alloy (Al 6063) reinforced with 10%wt of SiC_p and 3%wt of graphite. Taguchi based GRA was used to acquire grey relational grade for EDM operation. Importance of input variables was acquired by ANOVA based on grey relational grade. They found that that pulse current, voltage and pulse on-time were main variables influencing the quality of hybrid MMC whereas off-time was observed to be secondary factor. Gopalakannan and Senthilvelan (2013) [41] prepared aluminium MMNC reinforced with 0.5 wt% SiC nano-particles using ultrasonic cavitation. In this investigation, MMNC was machined on EDM by adopting face-centred central composite design technique. Chief factors that influence MRR were pulse current, on-time and off-time while voltage remained inconsequential. They noted that pulse current and pulse off-time found to have statistical importance on both EWR and SR. Higher off-time found to bring down EWR. Increase in SR and EWR was observed with increment in pulse current and on-time.

Puhan et al. (2013) [42] examined machinability attributes of Aluminum silicon carbide composite on EDM. Principal component analysis and fuzzy inference system combined with Taguchi technique were used for analysis. They observed that hardness of MMC increases with increment in % wt of SiC and mesh size. Process parameters were found to have great impact upon the multi-performance characteristic. Bhuyan et al. (2014) [43] examined the impact of input variables on response variables while machining Al-SiC12% MMC on EDM. The trail was conducted using central composite design method under several combinations of input variables. RSM technique was used to build up the mathematical model and to inter-relate the inputs variables with output variables. ANOVA technique was used for validation. They observed that peak current to be the most significant variable. MRR, TWR and SR increases with peak current. MRR and SR were observed to increase with on-time and flushing pressure while tool wear decreased.

Gugulothu et al. (2015) [44] studied machining of Ti-6Al-4V using EDM. Impact of utilizing graphite powder into the drinking water as dielectric medium was also investigated. Taguchi parameter design approach was employed for optimization of input parameters. ANOVA technique was conducted to recognize the importance of variables on measured response. Experimentations were carried out using modified dielectric fluid circulating system. It was found that MRR and SR increase with increment of peak current while it decreased less drastically with increase in graphite concentration. SR decreased with increase in graphite concentration and achieves maximum value and then reduces with further increase in graphite concentration. Krishna et al. (2015) [45] investigated optimization of the process variable of EDM for best values of SR, MRR and TWR when machining Al6061 (reinforced with 15.45% silicon carbide) using Cu electrode. A linear regression analysis was conducted on the data obtained from the tests. Multi objective optimization was conducted using fire fly algorithm (FFA) and the outcomes show that the best values of output parameters are obtained for low current value, high voltage value and low pulse on-time. MRR was noted to increase with increment in current. SR decreased with high current and tool wear rate increased.

Kalayarasan and Murali (2016) [46] investigated optimization of the input variables of EDM for maximum MRR and minimum EWR when machining silicon nitride-titanium nitride ceramic composites. Taguchi L9 orthogonal array to design the experiments was used. GRA and TOPSIS were applied for optimization of process variables. Current and on-time were noted to be the main parameters. Chandramouli and Eswaraiah (2017) [47] explored optimization of input parameters of EDM working on 17-4 precipitation hardening stainless steel using Cu-W electrode. Taguchi technique was employed to plan the experimentation format and tests were carried out accordingly. ANOVA technique was applied along with MINITAB 17 software for analyzing the impact of input variables on machining parameter. Results showed that on-time and current has noteworthy impact on MRR and SR whereas off-time has least influence.

Prasanna et al. (2017) [48] assessed performance of EDM using Cu electrode and kerosene as dielectric liquid for machining of AA7075 SiC MMC. Principal Component Analysis was used for optimization. MRR and TWR were noted to increase with increment in current while surface finish reduces immensely. Further, it was noticed that machining of AA7075-SiC MMC at high current resulted in increased TWR. Aharwal et al. (2018) [49] optimized of EDM parameters while machining Al-SiC using Cu electrode. Taguchi technique was employed for design of experiments and Genetic Algorithm was used for optimization. It was noted that MRR yields optimum value at higher values of current and lower values of voltage. SR was observed to be best when both qualities were low. Ubaid et al. (2018) [50] evaluated optimization EDM input parameters when machining SS 304 (ASTM A240). Signal-to-noise ratio was determined for each one of performance measures and then multi response performance index was generated using fuzzy logic inference system. Optimization of variables was done using ANOVA technique. It was observed that off-time and current has considerable impact on machining parameters. Behera et al. (2018) [51] examined optimization of AISI 304 stainless steel employing Taguchi technique. It was observed that MRR was directly related to the peak current and pulse on-time however depends conversely on the flushing pressure.

Peak current was the most noteworthy variable influencing MRR. Buschaiah et al. (2018) [52] characterised the EDM process when machining AISI 304 steel using Cu electrode. Taguchi technique was utilized to explore the affect of input variables on the output variables and to foresee the optimum set of parameters.

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SR was found to increase with increment in current. SR decreased with increment in on-time and electrode diameter. Kannan et al. (2018) [53] carried out electro discharge machining of Al7075/2 wt.% Al_2O_3 nano composite using Taguchi technique. The impact of input variable on machining variables was determined using ANOVA technique. They observed that maximum MRR and minimum EWR were obtained when Cu electrode was used. MRR increased with increase in current and pulse on-time while it reduced with increase in pulse off-time. EWR increased with increment in current and pulse on-time while it reduced with increase in off-time. Least SR was obtained by using brass electrode. SR reduced with increment in off-time. Singh (2018) [54] optimized the input variables of powder mixed EDM process for high carbon high chromium alloy steel (D2 steel) using Cu and Cu-Cr tool electrode. The design of the experiment was built by MINITAB 7 software. GRA technique was utilized to acquire the output response. Highest MRR and maximum TWR were accomplished with Cu-Cr tool. Minimum MRR and minimum TWR were attained while machining with Cu electrode. Minor cracks developed on the workpiece surface when Cu-Cr electrode was used. SR was found to be better with copper tool.

VIII. ANALYSIS AND DISCUSSION

After going through all above publications, it was noted that the majority of the investigators have tried to achieve improvement in EDM performance by improving MRR and SR and reducing EWR. However, there are still many areas of EDM which are required to be investigated. Investigations have been carried out in the direction of optimization of EDM process with the aim to find optimal parameters for the EDM for different materials under varying operating conditions to achieve improvement in the performance of EDM. Various performance measures have been chosen for improving the process and also developed mathematical models. Models have been developed by using Fuzzy Logic, Taguchi method, Neural Network, Design of Experiments (DOE), ANOVA, Genetic Algorithm etc. The optimal variables have been determined from the models and these variables gave better performance. However, these models are not generic; they are for the specific tool and workpiece combination.

It was observed that less work is available on machining of composite material like reinforce or lamina composite of different hard material compositions. Such materials find wide application in aircraft industry. Investigators have evaluated the machining parameters including MRR, TWR, SR and over cut. However, there is little works on the form tolerance of EDM i.e. cylindricity, perpendicularity and parallelism of holes machined.

IX. CONCLUSIONS

Electrical discharge machining is a subtractive type of non-traditional machining process that make use of electrical current for removal of stock from work sample. In this work, a comprehensive analysis of the available literature in the domain of EDM and optimization of its process parameters has been carried out. The literature has been analyzed and presented in such way that it can be conveniently used for further research work.

An overview have presented on how optimization of EDM process parameters can improve its performance in terms of material removal rate and surface finish. At the same time, reduction in tool wear rate is achieved. Gaps in the literature have been identified which can be beneficial for conducting research in the area of EDM.

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X. ABBREVIATIONS

Following abbreviations have been used in this work.

EDM	Electrical Discharge Machining
µ EDM	Micro Electrical Discharge Machining
MRR	Material Removal Rate
SR	Surface Roughness
EWR	Electrode Wear Rate
TWR	Tool Wear Rate
REWR	Relative Electrode Wear Rate
MMC	Metal Matrix Composite
MMNC	Metal Matrix Nano Composite
NSGA-II	Non-Sorting Genetic Algorithm-II
ANN	Artificial Neural Network

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ANOVA	Analysis of variance
RSM	Response Surface Methodology
GRA	Grey Relational Analysis
DOE	Design of Experiments
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

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