Addressing Trade-Off In The Expendables Encountered During Evaluation Of The Performance Metrics Of Electro-Discharge Machining

Abstract
The performance metrics namely, Material Removal Rate, Surface roughness, Electrode wear in the EDM calls for refined assessment of the input factors. The requirements, in contradiction with each other, pose a challenge in determining the optimal set points for the process. While a higher material removal rate is sought for efficiency, a lower electrode wear and a lower Ra value for the surface roughness is desired. This work shall look into the machining process parameters influencing the system, ranking of the parameters based on significance for a predefined output condition, simultaneous optimization for more than one response and applicability to similar processes in its domain. The analytical methodology for realizing the solution of the objective function shall be backed up with data offering response recorded during experimentation. Statistical tools shall be deployed for analysis of the data. ANOVA and ‘Regression’ shall be also employed. A suitable method like RSM shall be investigated to evaluate the multi-response problem at hand. Recommendation to be made towards conclusion of this work for assisting the ‘Process Engineer’ in harnessing this non-conventional machining process in the best possible manner.
1. INTRODUCTION

It is a non-traditional electro-thermal machining process, in which electrical energy is used to generate electrical spark and material removal occurs due to thermal energy produced by the spark. As such, thousands of sparks per unit second generated and each spark produces the tiny crater by heating and vaporization, thereby eroding the shape of the tool into the workpiece. The dielectric fluid flushes out the removed material particles and confines the spark. Work material is to be electrically conductive to be machined by EDM. The most common methods to evaluate machining performance in the EDM operation are based on the following performance characteristics: material removal rate (MRR), Surface Roughness and electrode wear ratio (EWR). A proper selection of these machining parameters can result in a higher MRR and lower EWR. Earlier, the desired machining parameters are determined based on experience or on handbook values. But these selected machining parameters are not always optimal or near optimal for that particular EDM environment. Therefore in EDM, it is very important to select machining parameters for achieving optimum machining performance. Various techniques, both conventional and non-conventional processes are employed to predict the optimum response parameters of the 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 workpiece material and the electrode material must be conductors of electricity. As such EDM is mainly used to machine high strength temperature resistant alloys and materials difficult-to-machine. EDM can be used to machine irregular geometries in small batches or even on job-shop basis.

The EDM process can be used in two different ways:

1.1 Conventional EDM

In the EDM process an electric spark is used to cut the workpiece, which takes the shape opposite to that of the cutting tool or electrode. The electrode and the workpiece are both submerged in a dielectric fluid, which is generally light lubricating oil. A servomechanism maintains a space of about the thickness of a human hair between the electrode and the work, preventing them from contacting each other. In EDM ram or sinker machining, a relatively soft graphite or metallic electrode can be used to cut hardened steel, or even carbide. The EDM process produces a cavity slightly larger than the electrode because of the overcut.

1.2 Wire-Cut EDM

The wire-cut EDM is a discharge machine that uses CNC movement to produce the desired contour or shape. It does not require a special shaped electrode, instead it uses a continuous-traveling vertical wire under tension as the electrode. The electrode in wire-cut EDM is about as thick as a small diameter needle whose path is controlled by the machine computer to produce the shape required.
1.3 Advantages of EDM

Conventional EDM machines can be programmed for vertical machining, orbital, directional, helical, conical, rotational, spin and indexing machining cycles. This versatility gives Electrical Discharge Machines many advantages over conventional machine tools.

- Any material that is electrically conductive can be cut using the EDM process.
- Hardened work pieces can be machined eliminating the deformation caused by heat treatment.
- X, Y, and Z axes movements allow for the programming of complex profiles using simple electrodes.
- Complex dies sections and molds can be produced accurately, faster, and at lower costs.
- The EDM process is burr-free.
- Thin fragile sections such as webs or fins can be easily machined without deforming the part.

2. LITERATURE REVIEW

I. Optimal parameter settings for rough and finish machining of die steels in powder-mixed EDM given by Anirban Bhattacharya & et. al studied to identify the appropriate parameter settings for rough and finish machined surface for EN 31, H11, and HCH Cr die steel materials in powder-mixed electric discharge machining process. The experiment was conducted on EDM machine. The experiment was undertaken to identify the process parameters that significantly affect the MRR, TWR and SR. For these experiment seven factors was used. Taguchi experiment design methodology was used. From the experiment concluded that the MRR dependent upon pulse off and on time and current. The electrode material had no effect on MRR, but combination with suspended powder affected MRR. SR was affected by pulse on time, current. EN31 had minimum MRR as compared to two other materials. Copper electrode with aluminum powder maximized MRR whereas Graphite powder had lower MRR but improved surface finish.
II. **Optimization of EDM process parameters using Taguchi method given by Azizul Bin Mohamad, Arshad Noor were investigated and optimization of EDM parameters using Taguchi method. In this study EDM machine was used to perform the experiment. Pure copper rod was used for electrode. Kerosene was used as dielectric fluid. High strength low alloy (HSLA) steel was chosen for workspace material. For each experiment the combination of 3 input parameters such as pulse on time, duty factor, discharge current all having three levels. Different settings of parameters were used to conduct the experiment. The SR was measured. For DOE Taguchi method is used. From S/N ratio lower the better performance characteristic was selected to obtain minimum SR. From ANOVA states that discharge current and pulse on time most effective on SR and duty factor least influencing the machining process quality.**

III. **Optimization of process parameters for Multi-performance characteristics in EDM of AL2O3 ceramic composite given by K.M Patel, Pulak M. etal studied optimization of EDM process parameters for Al2O3-SiCw-TiC ceramic composite of grey relational analysis based on Taguchi method. In this experiment electrolyte copper was used as electrode. Kerosene was used as dielectric fluid. Four controllable factors namely discharge current, pulse on time, duty cycle and gap voltage was selected. L9 nine experimental runs based on Taguchi methods orthogonal array performed. From experiment they analyzed that discharge current is most significant factor that affects grey relational grade. Increase in discharge current, surface roughness increases. The MRR increases with increase in pulse on time. With an increase in duty cycle, MRR increases and surface roughness increases which increases grey rational grade. With increase in gap voltage, both surface roughness and MRR increase which results into reduction of grey relational grade. The ANOVA of grey relational grade for multi performance characteristics revealed that the discharge current and duty cycle are the most influential parameters.**

IV. **Optimization of EDM process for Multiple performance characteristics using Taguchi method and Grey relational analysis given by Jang Hyuk Jung and Won Tae Kwon et.al investigated to find optimal machining conditions under which micro hole can be formed to a minimum diameter and minimum aspect ratio. Taguchi method was used to determine machining parameter and process characteristics. In this experiment EDM with 3 linear DC motor and controller were installed to control X, Y and Z directions. The electrode was produced by W-EDM machining. Electrode of 30-60 µm diameter used for experiment. For this experiment used of 400 µm thickness SS 304 work material. WC of 30 to 36 µm diameter and 1300 µm length of electrode used. Taguchi method was used. The machining parameters were voltage, capacitance, resistance, feed rate and spindle speed. L18 orthogonal array was selected. 2 levels of voltage with 3 level of acceptance resistance, feed rate and spindle speed were selected. It is stated that as spindle speed increase the debris was removed quickly. From experiment it was found that the electrode wear and the entrances and exit clearances have significant effect on diameter of micro hole when diameter of electrode was
identical. From gray rational analysis, obtained optimal machining conditions were input voltage 60V, capacitance of 680 pF, resistance of 500Ω, feed rate of 1.5 µm/s and spindle speed of 1500 rpm. Under these conditions, the micro hole 40 µm avg. diameter and aspect ratio 10 was machined.

V. Optimization of machining parameters in rotary EDM process by using the Taguchi method given by E. Aliakbari & H. Baseri determined the optimal setting of process parameters on rotary EDM. A rotary EDM process is performed with three variables of peak current, rotational speed of electrode and pulse duration. The work piece used for the experiment was X210Cr12. In this experiment, electrode rotating device consist of precision spindle, V belt drive mechanism. Experiment were conducted using pure copper in 3 types electrode without hole, electrode with hole, electrode with one eccentric hole. The experiment had been performed by using Taguchi method to evaluate the effects of input parameters on MRR, electrode wear rate (EWR), SR and overcut (OC). From this experiment concluded that input parameters of current, pulse on time, electrode rotational speed and electrode geometry are the most effective parameters on MRR, EWR, SR. Geometry of electrode is affected on flushing quality while the electrode is rotary. OC of the produced parts using the electrode with 2 holes off centre is better than other electrodes due to better washing which causes faster removal of chips from machining area. Increasing whole numbers the area of electrode is decreased and therefore MRR, SR and EWR increase.

VI. Optimization of machining characteristics in electric discharge machining of 061Al /Al2O3p/20p composites by grey relational analysis given by S. Singh investigated design of experiments and grey relational analysis approach to optimize parameters for electrical discharge machining process of aluminum metal matrix composites. The spark erosion oil was used as dielectric fluid with flushing pressure of 1.15 Kgf/cm2. For this experiment 6061Al/Al2O3p/ 20p aluminum metal matrix composites was used. In this experiment two levels and five control factors having three levels each were chosen. For this experiment control factors were pulse current, pulse on time, duty cycle, gap voltage and tool electrode lift the with three levels each. The Taguchi orthogonal array selected for experimentation. Experiment results have shown that MRR, tool were rate, SR in EDM process can be improved effectively through proposed approach. GRA approach successfully applied to determine process parameters at multiple quality requests.

VII. Optimisation of machining parameters for hard machining: grey relational theory approach and ANOVA given by Bala Murugan Gopalsamy & Biswanath Mondal studied experimental investigation for machinability study of hardened steel and to obtain optimum process parameters by grey relational analysis. Taguchi L18 orthogonal array is investigated in this paper with grey relational theory to analyze process parameters from 18 experiments for rough and finish machining individually by varying four process parameters, i.e. cutting speed, feed, depth of cut, and width of cut. For rough machining the process parameters are optimized with respect to volume of
material removed, tool wear and tool life by using GRA. The most influencing parameters are then noticed. In this experiment pre-annealed tool steel with hardness of 55 HRC workpiece was used. The results were compared with ANOVA. It has been observed that the width of cut and depth of cut are the most influencing parameters in rough machining. For finish machining the cutting speed is the most influencing parameter.

VIII. **ONEWAY: A BASIC program for computing ANOVA from group summary statistics given by JOSEPH S. ROSSI.** This paper describes a basic program for computing ANOVA from group summary statistics. Such program fill wide range of user needs, including factorial designs, repeated measures, multiple dependent variables, mixed model designs, nested designs, inclusion of covariates and assorted follow up tests. A BASIC ANOVA program for which group summary data means standard deviations and simple sizes are used as input. In statistical tests based on group data two sample t tests and the chi-square test of independence can be calculated directly from group data. Gorden (1973) have been the first publish the appropriate equations, but there was an error in his equation which corrected in Rossi (1987b). A simple interactive BASIC computer program was developed. The program asks the user how many groups are to be included in the analysis and the prompts the user to supply the mean, the standard deviation and the sample size for each group. Output is provided in familiar ANOVA summery. P value can be determined using common available tables of F-distribution. The program also provides a modified t value for heterogeneous variance. The program was developed on an IBM PC/AT microcomputer. Accuracy tests conducted by the author suggest that error rates of less than 1% can be expected at least three significant digits are used.

IX. **Multi-objective optimization of process parameters for helical gear precision forging by using Taguchi method given by Wei Feng and Lin Hua-In this paper, multi-objective optimization design for the helical gear precision forming was proposed based on finite element method and taguchi method. The max. forging force and die-fill quality are considered as the optimal objectives. The maximum forging force and die-fill quality are considered as the optimal objectives. The optimum parameters combination was obtained through SN ratio analysis, ANOVA and FEM simulation. It was shown that the significant parameters affecting the helical gear warm forging process such as deformation temperature, friction coefficient and punch velocity can be easily recognized by performing the experiments which are designed based on orthogonal array and taguchi method. For the given helical gear forming process, the optimum combination of process parameters can be determined through modified Taguchi method to obtain minimum values of maximum forging force and minimum distance.

X. **Optimization of turning parameters for surface roughness and tool life based on Taguchi method given by Ahmet Hascalik. Ulas. Caydas-This paper demonstrate application of Taguchi parameter design in order to identify the optimum surface roughness and tool life performance with a particular performance with particular
combination of cutting parameters in turning titanium alloy. The Ti-6Al-4V alloy was used. CNC lathe machine was used for experimentation. Tungsten carbide with 6% cobalt as the binder was used as cutting tool material. The experiment conducted under varying cutting speeds, feed rate, and depth of cut. An orthogonal array, SN ratio, and ANOVA were employed to study the performance characteristics. Based on ANOVA results, the highly effective parameters was feed rate on both SR and tool life. Tool life was affected by cutting speed whereas feed rate and depth of cut have a significant statistical influence.

3. PROBLEM DEFINITION
The type of performance metric desired as an outcome has a direct influence on the set points of any given input parameter of a system-EDM, in this case. While one performance metric or response shall call for a certain value for an input parameter, another would call for grossly different value for the same parameter. The industry, in general, seeks the best trade-off while dealing with conflicting needs to be addressed simultaneously. While a higher rate of material removal is desired to enhance efficiency, the surface roughness value might need a tight control as a deliverable. A balanced process could address such requirements through assignment of appropriate values to the parameters precise control of the process. Any Sub-optimal setting shall results in reduced productivity along with a non-precise response (output). Research work needs to be pursued on these lines to realize the best trade off in a multi-response scenario.

4. SCOPE OF WORK / OBJECTIVES
The objective of the present work is to investigate the effects of the various EDM process parameters on the machining quality and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized.

- Study the basic principle of EDM process, significant process parameters and materials for workpiece and tool
- Identify the input parameters and levels of input parameters for conducting the experiments to determine effect over the response parameters
- Perform analysis using optimization tool such as Taguchi method/ ANOVA / RSM for the readings recorded during experimentation
- Evaluate the results
- Recommend the optimal set-points
- Conduct experiment for validation for results

5. METHODOLOGY
The literature survey has revealed that a little research has been conducted to obtain the optimal levels of machining parameters that yield the best machining quality in machining of difficult to machine materials like hot die steel H-13. The hot die steel H-13 is
extensively used for hot-work forging, extrusion, manufacturing punching tools, mandrels, mechanical press forging die, plastic mould and die-casting dies, aircraft landing gears, helicopter rotor blades and shafts, etc. The consistent quality of parts being machined in electrical discharge machining is difficult because the process parameters can not be controlled effectively. These are the biggest challenges for the researchers and practicing engineers. Manufacturers try to ascertain control factors to improve the machining quality based on their operational experiences, manuals or failed attempts. The working ranges and levels of the EDM process parameters are found using one factor at a time approach. Using minitab software interface, Taguchi technique has been used to investigate the effects of the EDM process parameters and subsequently to predict sets of optimal parameters for optimum quality characteristics. The response surface methodology (RSM) has been used to develop the empirical models for response characteristics. Desirability functions have been used for simultaneous optimization of performance measures. Also, the Taguchi technique and utility function have been used for multi-response optimization. Confirmation experiments are further conducted to validate the results.

5.1 Steps For Methodology

i.) Develop the experimental set up for providing varying range of input parameters in EDM and measuring the various responses on-line and off-line

ii.) Identify the working ranges and the levels of the EDM process parameters (pilot experiments) affecting the selected quality characteristics, by using one factor at a time approach

iii.) Study the effects of EDM process parameters on quality characteristics viz. material removal rate, surface roughness, Spark gap and dimensional deviation while machining H-13 hot die steel

iv.) Using Mini Tab software, Taguchi parameter design approach would be used to obtain the following objectives

v.) Prediction of optimal sets of EDM process parameters

vi.) Prediction of optimal values of quality characteristics

vii.) Prediction of confidence interval (95%CI)

viii.) Development of mathematical model using Response surface analysis

ix.) Development of multi objective optimization models using Taguchi technique

x.) Determination of optimal sets of EDM process parameters for desired combined quality characteristics

xi.) Experimental verification of quality characteristics optimized in different combinations

5.2 Treatment Planned For This Work

i.) Application: High Pressure Die Casting

ii.) Work piece material – H13 Hot die Steel

iii.) Tool Material – Copper
iv.) Input Parameters – Discharge Current (Amp), Pulse on Time (sec), Pulse off time (sec)

v.) Parameters to kept constant – Spark gap, Lubricating oil, work piece material, tool material

vi.) Response parameters – MRR, Tool wear, Surface roughness

vii.) Analytical Software – Data to be treated using ´MiniTab´

6. EXPERIMENTATION

Figure 2 shows the typical setup for Electric Discharge machining (EDM). EDM consists of an electrode and the work piece. Both work piece and tool are submerged in a dielectric fluid like EDM oil/ kerosene/ deionized water. About a thin gap is maintained between the workpiece and the tool by a servo system shown in Figure2. The work piece is anode and tool is cathode.

When the current is switched on, an electric tension is created between the two metal parts. Electrons and positive ions get accelerated, creating a discharge channel that becomes conductive. It is then at this point when the spark jumps causing collisions between electrons and ions creating a channel of plasma. Electrical resistance suddenly drops of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters. The moment spark occurs sufficiently pressure developed between tool and work due to which high temperature is reached and then metal is eroded at that high temperature and pressure. Fig.3 shows the pictorial representation of EDM machine.
7. VALIDATION
For validation purpose, the experimentation would be carried out on optimized set of parameters obtained from analytical method. The surface roughness value can be find out using surface roughness tester. The surface roughness value obtained from experimentation would be compared with analytical method.

9. CONCLUSION
• From literature review, it is concluded that Spark gap, Current, Spark ON/OFF time, dielectric fluid, workpiece material, electrode materials are the input parameters for EDM process.
• The response parameters identified through the Literature Review are Material Removal Rate (MRR), Surface roughness (Ra value), Tool wear
• Taguchi’s method, ANOVA, Regression analysis, RSM these are the statistical tools to be used to obtain optimum parameters combination for desired response parameter.
• The level of importance of machining parameters and their individual contributions on Surface Roughness and tool wear can be determined using Analysis Of Variance (ANOVA).

10. REFERENCES
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Atish B. Mane, Dr. Pradeep V. Jadhav, Swapnil S. Kulkarni: Addressing Trade-Off In The Expendables Encountered During Evaluation Of The Performance Metrics Of Electro-Discharge Machining


Biography

Atish B. Mane. Ph.D. Research Scholar at Bharati Vidyapeeth Deemed University, Pune

Dr. Pradeep V. Jadhav is Associate Professor in the Department of Production Engineering, Bharati Vidyapeeth University College of Engineering Pune, India. He has 12 years of teaching experience in the college level engineering education since 2003. He has published seven papers, international Journals, one national journal and fifteen papers in international conferences. His area of Interest is Advanced Manufacturing Processes.

Mr. Swapnil S Kulkarni Director, Ethika Engineering Solutions India Pvt. Ltd., Pune. The Company offers Engineering Services and Manufacturing Solutions to Automotive OEM’s and Tier I and Tier II Companies. He is a Graduate in Industrial Engineering with PG in Operations Management. With around 20 years of working experience in the domain of R&D, Product Design and Tool Engineering, he has executed projects in the Automotive, Medical and Lighting Industry. His area of interest is Research and Development in the Engineering Industry as well as the emerging sector of Renewable Energy.