A Literature Review on Optimization of Process Parameters of Wire-Cut Electric Discharge Machine using Tungsten Die Tool Steel using Taguchi Method)

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Abstract— Wire-cut Electric Discharge Machine (WEDM) process is one of the most widely used non-traditional machining processes in current manufacturing. This work presents the effect using different combinations of input parameters like pulse on time, pulse off time, output responses like kerf width, MRR, surface roughness (Ra) and the surface topography on different types of materials using design of experiments. A standard orthogonal array in Taguchi is used as a technique in design of experiments. The selection of the parameters depends on the requirements based on a better surface roughness or a maximum material removal rate. Hence an appropriate combination of the variables can be selected accordingly.

Key words: Roughness, MRR, Orthogonal Array, ANOVA Table

I. INTRODUCTION

Wire electrical discharge machining or WEDM is a metal working process, with the help of which a material is separated from a conductive work piece, by the process called electrical erosion. The wire is not in touch with the conductive work piece. The wire electrode generate a path on the work piece, which is slightly larger than the wire. Mostly a 0.010 inch (0.25 mm) wire is used which made a 0.013 to 0.014 inch gap. The wire electrode once passed through and cannot be reused.

Electrode wire is connected to the cathode of impulse power source, and work piece is connected to the anode of impulse power source. When the work piece is approaching insulating liquid and gap between them getting small to a certain value, insulating liquid was broken through; very shortly, discharging channel are formed, and electrical discharging happen. This result in high temperature instantaneously, temperature reaches up to above 10000 degree centigrade; the eroded work piece is cooled down swiftly in working liquid and flushed away. Wire electrode is generally made up of copper, brass or tungsten of diameter 0.05mm to 0.3mm, which is capable to achieve very small corner radii. When the equipoise voltage is applied across the two electrode separated by a dielectric fluid, the latter starts breaking down. The electrons, so liberated are accelerated in presence of the electric field and starts colliding with the dielectric molecules, causing the latter to be robbed off their electrons.

II. LITERATURE WORK AS SUMMARIZED BELOW

As the popularity of WEDM increases due to its advantages over traditional machining, a lot of researches have been done on WEDM in the recent years. Extensive research on WEDM led us to a better understanding of effect of each process parameters on response characteristics. In this chapter the author reviews the published literature relevant to the topic of the thesis under following considerations.

- Material Removal mechanism
- Surface roughness
- Parameter Optimization for single response characteristics
- Design of Experiments and Taguchi method

A. Some of the work related to the present study is discussed in the following paragraphs:

Anish Kumar et al, 2012had used a pure titanium (grade-2) for investigation on WEDM. Experiment has been made to improve the response variable i.e. surface roughness in the WEDM process using a response surface methodology. Six parameters i.e. pulse on time, pulse off time, peak current, spark gap voltage, wire feed and wire tension have been varied to investigate their effects on surface roughness. The surface roughness has been optimized using a multi-response optimization technique. The ANOVA (Analysis of Variance) has been applied to identify the significances of developed model. The test results confirms the validity and adequacy. Finally, the optimum parametric setting has been designed for the optimization of process.[3]

Aniza Alias et al, 2012 the aim of this paper is to show , how the Improper electrical parameters settings can affects the processing efficiency and surface roughness due to the arcing phenomenon that leads by discharge point of focus. Objective of the paper is to uncover the influences of three different machine speeds which are 2 mm/min, 4 mm/min and 6 mm/min with a constant current (6A) with WEDM of Titanium Ti-6Al-4V. The effects of the different process parameters on the kerf width, material removal rate, surface roughness and the surface topography are also discussed. The best combination of the machining parameter viz. machine feed rate (4 mm/min), wire speed (8 m/min), wire tension (1.4kg) and voltage (60V)were identified. The paper told the importance of the process parameters and different machining conditions on k_{erf} width, MRR, surface roughness (Ra) and the surface topography. [5]

Aniza Alias et al, 2012investigate the influences of the feed rate on the performance of WEDM on Titanium Ti-Al-4V. Brass wire was used as the electrode in this study. The results on the k_{erf} width, material removal rate and surface roughness are graphically shown. The best combination of the machining parameter viz. machine feed rate (4 mm/min), wirespeed (8 m/min), wire tension (1.4kg) and voltage (60V) were has to be identified. The selection of the parameters depends on the requirements basedon a better surface roughness or a maximum material removal rate. Hence an appropriate combination of the variables can be selectedaccordingly.[4]

Jaganathan P et al, 2012show how to get the optimum surface finishes at the optimum cutting speed. In this paper EN31 is taken for the study. The design of the experiments (DOE) is being done in Taguchi L27 orthogonal array (OA). In WEDM process of rough machining gives the lesser accuracy and finish machining gives the fine surface finish, but it reduces the machining speed. Hence we have to improve the MRR and reduce the surface finish (Ra) as the objective, which is done by Taguchi method.[9]

Muthuraman.V et al, 2012the aim of this paper is to be optimized the response characteristics of WC-Co composite on the Wire electro Discharge machining (WEDM). In WC-Co, Tungsten and Carbide are hard wear resistant materials; cobalt is the binder that binds them made through a powder metallurgy technique. To derive the best operating inputs in order to attain the best output, the influential parameters and their interactions needs to be studied. The experiments were conducted in Taguchi L32 orthogonal array, with the four levels of the input parameters on, cobalt percentage, on time, off time, wire feed, wire tension, ignition current and dielectric pressure. The outputs is studied in this work were material removal rate (MRR) and surface roughness (Ra) which are the important in any machining process. ANOVA table is constructed to analyses the result.[14]

S.Boopathi et al, 2012used oxygen as a dielectric medium in WEDM. The demonized water is replaced by the oxygen as the dielectric medium to ameliorate the environmental impact in the machining surroundings and to mitigate the health hazardous to the operators. The experimental studies have been conducted by varying the pulse width (Tw), pulse interval (Ti), open circuit voltage(V), and discharge current (I). The values of the machining parameters have been obtained by using the Taguchi design of the experimental method. The implication of the input parameters of the material removal rate (MRR) and Surface Roughness (Ra) has been investigated by using the Analysis of Variance (ANOVA). The optimum output of machining parameter values are predicted by using Taguchi analysis and verified by the conformation of experiments.[22]

Adem Çiçek et al, 2012study the effects of deep cryogenic treatment and drilling parameters on the surface roughness and roundness error were investigated inthe drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. In addition, to the optimal control factors for the whole quality were determined by using the Taguchi technique. Two cutting tools, the cutting speeds and feed rates were considered as control factors, and L8orthogonal array was determined for the experimental trials. Multiple regression analysis was employed to the derive the predictive equations of the surface roughness and roundness error achieved via the experimental design. Minimum surface roughness and roundness error were obtained with treated drills at14 m/min cutting speed and 0.08 mm/rev feed rate. Confirmation experiments showed that the Taguchi method precisely optimized the drilling parameters in drilling of stainless steel.[2]

V. Muthuraman et al, 2012in the present work author uses a popular tool-die material O1 steel that is subjected to WEDM to be optimized the response characteristics. The experiments were arranged on L32 orthogonal array, operations were performed at the different cutting conditions of pulse ON time, pulse OFF time, the wire feed, flow rate, wire tension and voltage. The outputs analyzed were, the material removal rate (MRR), wire-wear ratio, surface roughness and dimensional deviation. Experimental results prove that the derived machining parameters satisfies the real requirement in practice.[28]

Pichai Janmanee, Apiwat Muttamara, 2011this paper is an investigation on the optimal process parameters to minimize the micro crack density (Cr.S.Dn), electrode wear ratio (EWR) and maximize the material removals. To reduce the number of experiments, the Taguchi design using an L9 orthogonal array was used. Analysis of variance (ANOVA) and signal-to-noise (S/N) ratio were performed and are calculated, respectively. The important control parameters were the following: the discharge current, off time, and open-circuit voltage. Using the Taguchi approach, the significant factors of MRR, EWR, Cr. S. Dn. and their associated levels are on each response were determined by ANOVA analyses. The discharge current parameters mainly affect the MRR, EWR and Cr. S. Dn. Additional experiments confirmed the optimal process parameters at the 95% of the confidence interval. Micrographs from a scanning electron microscope (SEM) were used to study the density of the micro cracks on the surfaces machined by EDM.[15]

Pujari Srinivas Rao, Koona Ramji, 2011in this paper machining of the Aluminum-24345 on a Wire-cut electric discharge machine is considered. The low rigidity and the high material removal rate of aluminum alloys offers a challenging task in obtaining a better surface finishes. Experimentation has been done by using Taguchi's L18 orthogonal array under the different conditions of parameters. The response of surface roughness is considered for improving the machining efficiency. Optimal combinations of the parameters were obtained by this method. [16]

A.Thillaivanan et al, 2010reported the complexity of electrical discharge machining process which is a very difficult to determine optimal cutting parameters for improving the cutting performance. It is important to optimized the operating parameters in machining, particularly for operating unconventional machining procedure like EDM.A suitable selection of machining parameters for the electrical discharge machining process on the operators' technologies and the experience because of their numerous and diverse range. Machining parameters tables provided by the machine tool builder cannot meet the operators' requirements, since for an arbitrary desired machining time for a particular job; they do not provides the optimal machining conditions. An approach to determine the parameters setting is proposed. Based on the Taguchi parameter design method and the analysis of variance, the significant factors affecting the machining performances such as the total machining time, oversize and taper for a hole machined by EDM processes, are determined. Artificial neural networks are highly flexible modeling tools with having an ability to learn the mapping between the input variables and the output feature spaces. The superiority of using artificial neural networks in modeling machining processes making it easier to model the EDM process with dimensional input and output spaces. On the basis of the developed neural network model, for a required the total machining time, oversize and taper the corresponding process parameters to be set in the EDM by using the developed and trained ANN are determined.[1]

Muthu Kumar V et al, 2010 optimize the Wire Electrical Discharge Machining process parameters ofIncoloy800 super alloy with the multiple performance characteristics such as the Material Removal Rate (MRR),surface roughness and K_{erf} based on the Grey–Taguchi Method. The processes parameters are considered in this research work are the Gap Voltage, Pulse On-time, Pulse Off-time and Wire Feed. Taguchi's L9 Orthogonal Array was used to conduct the experiments. Optimal levels of process parameters were identified using Grey Relational Analysis and the relatively significant parameters were also determined by Analysis of Variance. The variation of the output responses with the process parameters were mathematically modeled by using a non-linear regression analysis method and the models were checked for their adequacy. Result of the confirmation experiments shows that the established mathematical models can be predicted the output responses with reasonable accuracy. [12]

Muthu Kumar V et al, 2010discuss about the process optimization. Process optimization is a significant and contributing step towards the process efficiency as it gives way for an improved overall productivity. In this paper, the optimization of parameters used in the CNC Wire-Cut Electrical Discharge Machining (Wire-Cut EDM) process, for the Titanium Alloy (Ti–6Al–4V) by utilizing the Taguchi method and the Grey Relational Analysis (GRA) are studiously reported. Performance and Characteristics such as the MRR (Material Removal Rate) and the Surface Roughness (which are normally used in the evaluation of the 'machining effects') are chosen to be evaluated the machining 'effects' in this study. The correlated input parameters such as the Gap Voltage, Pulse On-time, Pulse Off-time and the Wire Feed are included in this study. Taguchi's L9 Orthogonal Array (OA-L9) method was used in this experimentation for optimizing the parameters of the Wire-Cut EDM process. Optimal levels of the process parameters were identified using Grey Relational Analysis (GRA) and the relatively significant parameter/s was also determined by Analysis Of Variance (ANOVA). Optimization Process parameters simultaneously leading to a higher MRR (Material Removal Rate) with a decreased Surface Roughness were also verified through the confirmation of experiment, for validation of the test results. Experimental results have shown that the conventional responses experienced in the traditional Wire-Cut EDM process can be effectively improved by adopting the Grey based Taguchi approach technique.[13]

R.N. Ahmad et al, 2010in this investigation the machinability of the Aluminum Matrix Composite (AMC) using Wire-cut Electric Discharge Machining (WEDM) machine is constructed to achieve a better stability and high productivity of the manufacturing process . The aim of this project is to determining the most optimum machining parameter that will be increased the machinability of the AMC based on material removal rate (MRR). A series of experiments have been conducted on AMC reinforced 5 % alumina (Al_2O_3) with the dimensions 100mm x 3 mm x 4 mm. The test specimens have been cut by using different machining parameter combinations on the Sodick AQ327L WEDM machine in the Teaching Factory of University Malaysia Perlis (UniMAP).The Full Factorial Design of Experiment approach with two levels were used to determine the combination of the machining parameter based on Pulse-off time (µs), the Servo Voltage (V), and Wire Tension (gf/mm). The result of the calculated MRR was analyzed using Regression Analysis Method to determine the mathematical model between the machining parameter and machining.[18]

R. Ramanujam et al, 2010paper show the methodology DFA was used for the optimization of the machining parameters on turning the AL-15%SiCp metal matrix composite. Optimization of machining parameters was done by an analysis called the desirability function analysis. Taguchi's L27 orthogonal array is used for the experimental design. The machining process parameters such as the cutting speed, feed rate and depth of cut are optimized with the multiple performances consideration namely the surface roughness and the power consumption. The optimum machining parameters have been identified by a composite desirability value obtained from DFA as the performance index, and significant contribution of a parameter can then be determined by the ANOVA. Confirmation test is also conducted to validate the desired test result. Experimental results have shown that machining performance can be improved effectively through this approach.[19]

S. K. Sinha 2010this investigation shows the effect of the wire lag in machining with WEDM. The main cause of inaccuracy is wire-lag, the cause and effect of which is described in the present work, along with a technique to solve the problem in the straight cutting. In a subsequent paper, software approaches (since the problem gets too complicated) for improvement of the accuracy in contour cutting is described.[23]

H. Singh, R. Garg, 2009purpose of this paper is to study the effects of the various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), gap voltage (SV), peak current (IP), wire feed (WF) and the wire tension (WT) have been investigated to reveal their impacts on the material removal rate of hot die steel (H-11) using one variable at a time approach. The optimal set of process parameters has also been predicted to maximize the material removal rate. The experimental studies were performed on the ELECTRONICA SPRINTCUTWEDM machine to optimize the material removal rate (MRR) which is directly increases with increase in pulse on time (TON) and peak current (IP) while it decreases with increase in pulse off time (TOFF) and the servo voltage (SV)process capable of accurately machining parts which have the varying hardness, complex shapes and sharp edges that are very difficult to be machined by the traditional machining processes. The practical technology of the WEDM process is also based on the conventional EDM sparking phenomenon utilizing the widely accepted non-contact technique of material removal.[8]

S. Thamizhmanii et al, 2007the purpose of this research paper is to be focused on the analysis of optimum cutting conditions to get lowest surface roughness in turning SCM 440 alloy steel by Taguchi method. Experiment was designed using the Taguchi method and 18 experiments were designed by this process and experiments were conducted. The results are analyzed using the analysis of variance(ANOVA) method. Taguchi method has shown that the depth of cut has significant role to play in producing the lower surface roughness followed by the feed. The Cutting speed has the lesser role on surface roughness from the tests. The vibrations of the machine tool, tool starts chattering are the other factors which may be contributed to a poor surface roughness to the results and such factors are ignored for analyses. The results obtained by this method will be useful to other researches for similar type of study and may be the eye opening for further research on the tool vibrations, cutting forces etc.[26]

Fuzhu Han et al, 2007describes the influences of the machining parameters (including the pulse duration, discharge current, sustained pulse time, pulse interval time, polarity effect, material and dielectric) on surface roughness in the finish cut of WEDM. Experiments proved that the surface roughness can be improved by decreasing the both pulse duration and discharge current. When the pulse energy per discharge is constant, short pulses and long pulses will results in the same surface roughness but the dissimilar surface morphology and different material removal rates. The removal rate when short pulse duration is use than when the pulse duration is longer. Moreover, from the single discharge experiments, we had found, that a long pulse duration combined with a low peak value could not be produced craters on the work piece surface any more when the pulse energy has reduced to a certain value. However, the condition of short pulse duration with a high peak value still could produce clear a craters on the work piece surface. This indicates that a short pulse duration is combined with a high peak value can generate a better surface roughness, which cannot be achieved with the of long pulses. In the study, it was that the also found that reversed polarity the machining with the appropriate pulse energy can improves the machined surface roughness by somewhat better compared with normal polarity in finished machining, but some copper from the wire electrode is accreted on the machined surface.[7]

S S Mahapatra, Amar Patnaik, (2006) in this paper author optimizes the process parameter like, dimensional accuracy and surface finishes with the help of genetic algorithm. Process parameters are largely depending on process parameters such as discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate. An experimental study has been carried out on a Robofil 100 WEDM machine to determine various significant control factors and their interactions that affect the machining performance such as the metal removal rate (MRR) and surface finish (SF) based on the Taguchi method. The relationship between the control factors and the responses like MRR and SF are established by means of a non-linear regression analysis resulting in a valid mathematical model. Finally, a genetic algorithm, a popular revolutionary approach, is used to optimize the wire electrical discharge machining process with the multiple objectives. The study of demonstrates that the WEDM process parameters can be adjusted to achieve a better metal removal rate and surface finish simultaneously.[24]

S. S. Mahapatra & Amar Patnaik, (2006) wire electrical discharge machining (WEDM) is extensively an used in machining of a conductive materials when precision is of prime importance. Rough cutting is an operation in WEDM which is treated as a challenging one because improvement of more than one machining performance measures viz. the metal removal rate (MRR), surface finish (SF) and cutting width (k_{erf}) are sought to obtained in precision work. Using the Taguchi's parameter of design, significant machining parameters are affecting the performance measures are identified as the discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow. It has been observed that a combination of the factors for optimization of each of the performance measure is different. In this study, the relationship between the control factors and responses like MRR, SF and k_{erf} are established by means of a nonlinear regression analysis, which is resulting in a valid mathematical model. Finally, a genetic algorithm, is a popular revolutionary approach, is employed to optimize the wire electrical discharge machining process the with multiple objectives. The study demonstrates that the WEDM process is a parameters that can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously.[25]

Y.M.Puri and N.V.Deshpande, (2004)in this paper author uses number of fuzzy logic in the Taguchi method to optimize Electro Discharge Machining (EDM) process with a multiple quality characteristics. Rough machining with EDM gives a poor surface finish and has number of micro cracks and pores. Finished machining gives a better surface finish but with a very poor machining speed (MRR). Hence achieving a higher cutting speed along with the better surface finish can be considered as a multi-objective optimization problem. the Taguchi method has becoming a powerful tool in the design of experiments as it had improved performance characteristics by optimizing the process parameters and reduced the sensitivity of the system performances to the noise. However, the Taguchi method can be optimized single performance characteristics at a time. Hence the Taguchi approached has coupled with a fuzzy logic for optimization of a multiple quality characteristics. Fuzzy reasoning of the multiple performance characteristics has been developed based on a fuzzy logic. As a result optimizations of it complicated multiple performance characteristics is transformed in to the optimization of a single response performance index. Electronic EZEECUT-WEDM setup is used as an experimental machine. The work-piece is a material used as High-Chromium-High-Carbon die steel. Experimental results confirmed that this approach is simpler, effective and efficient for a simultaneous optimization of multiple quality characteristics i.e. MRR and surface finishes in EDM.[29]

Kevin N. Otto et al, 1991the Taguchi method of a product design is an experimental approximation to minimized the expected value of target variance for certain classes of problems. the Taguchi's method is extended to designs which involves the variables each of which has a range of values all of which must be satisfied (necessity), and designs which involve the variables each of which has a range of values any of which might be used (possibility). Tuning parameters, as a part of a design process, are also demonstrated within the Taguchi's method. The method is also extended to solve the design problems which constraints, involving the methods of constrained optimization. Finally, the Taguchi method uses a factorial method to search the designed space, with a confined definition of an optimal solution. This is compared with other methods of searching the design space and their defination of an optimal solution.[10]

Resit Unal, Edwin B. Dean,1991The purpose of this paper is to present an overall view of the Taguchi methods for improving the quality and reduction in the cost, it describes the current state of applications and its role in identifying the cost sensitive design parameters.[17]

B. Papers referred above many conclusion can be drawn as these summarized below

After gone through several research papers it has been found that lot of research work had been done on WEDM in different fields. Several research papers have been published on process parameter design, for different response characteristics. Main responses of characteristics in the WEDM are the surface finish, cutting speed, material removal rate. A huge amount of work has been carried out, concentrating on the improvement of the inaccuracy caused by the wire through the application of an adaptive control system. One possible new WEDM challenges and future work will be steered towards attaining the higher machining efficiency by acquiring a higher cutting speed (CS), material removal rate (MRR) and low surface roughness (SR), with the low wire consumption and frequency of wire breakage.

The optimal parameter of setting for CS, SR, MRR and dimensional accuracy is different for the different materials and these are set in experimentally. In this study process parameters are optimized simultaneously for different response characteristics in die cutting to reduced the total manufacturing time.

1) The surface roughness can be improved by decreasing both pulse duration and discharge current.
2) This indicates that a short pulse duration combined with peak value can be generate both surface roughness which cannot be achieved with long pulses.
3) Reversed polarity machining with appropriate pulse energy can improved machined surface roughness somewhat better compared with normal polarity in finish machining some copper from wire electrode is accreted on the machined surface.
4) The hardness and strength of the works material are no longer the dominating factors that effect the tool wear and hinder the machining process.
5) The increasing pulse duration and open circuit voltage increase the wire wear ration where as the increasing wire speed decreases it

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