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Process Optimization of Wire Electrical Discharge Machining - a Review

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Abstract – Wire Electrical Discharge Machining (WEDM) is widely used in industry for the macro and micro-machining of parts with complex and irregular shapes, requiring high profile accuracy and tight dimensional tolerances. As WEDM process is not affected by material hardness, compared to traditional machining technologies, it can be effectively used to machine a large variety of materials including cemented carbides, sintered materials as well as difficult to machine aerospace alloys such as Nickel or Titanium alloys. Response Surface Methodology (RSM) approach and Taguchi`s method are the procedure for determining the relationship between various process parameters with the different machining criteria and exploring the effect of these process parameters on the coupled responses. An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as brain processes information. This study provides a review on optimization of machine parameters by different techniques.

Keywords- Machining Wire cutting, Surface roughness, Material removal rate, Optimization, Response Surface Methodology, Taguchi`s method, Artificial neural network.

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1. INTRODUCTION

In recent years Wire Electric Discharge Machining (WEDM) has become an important non-traditional machining process because of its ability to machine precise, complex and irregular shapes easily with the help of setting optimum parameter of the WEDM machine. Wire EDM, or electrical discharge machining, is a high-precision method for cutting nearly any electrically conductive material [1].

A thin, electrically-charged EDM wire held between upper and lower mechanical guides forms one electrode, while the material being cut forms second electrode. Electrical discharge between the wire and the work piece creates sparks [2].

As the charged wire never makes physical contact with work piece in EDM machining, there are no cutting forces involved, making it possible to manufacture extremely small and or delicate parts. Parts that require levels of accuracy and intricacy which traditional machining cannot achieve can easily be produced via wire EDM. Response Surface Methodology approach is the procedure for determining the relationship between various process parameters with the different machining criteria and exploring the effect of these process parameters on the coupled responses. An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as brain processes information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems [3].

Technologically advanced industries like aeronautics, automobiles, nuclear reactors, missiles, turbines etc., require materials like high strength temperature resistant alloys having higher strength, corrosion resistance, toughness, and other diverse properties. The phenomenon of erosion of metals by electric spark was first noticed by Joseph Priestily in 1878 but this was not used for machining of metals until 1930s. Controlled machining of metals by electric sparks was first done by Lazarenko in Russia in 1944. One of the most widely used Non-Conventional Machining process in industry is Electrical Discharge Machining (EDM). Electric Discharge Machining is a non-traditional concept which is based on the principle of removing material by means of repeated electrical discharges between the tool termed as electrode and the work piece in the presence of a dielectric fluid. Electrical Discharge Machining (EDM) uses thermal energy to achieve a high-precision metal removal process from a fine, accurately controlled electrical discharge. The electrode is moved towards the work piece until the gap is small enough so that the impressed voltage is enough to ionize the dielectric. Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece [4]. The material is removed with the erosive effect of the electrical discharges from tool and work piece. EDM does not make direct contact between the electrode and the work piece thus it can eliminate mechanical stresses, chatter and vibration problems during machining [5]. WEDM is considered as a unique adoption of the conventional EDM process which comprises of a main worktable, wire drive mechanism, a CNC controller, working fluid tank and attachments.

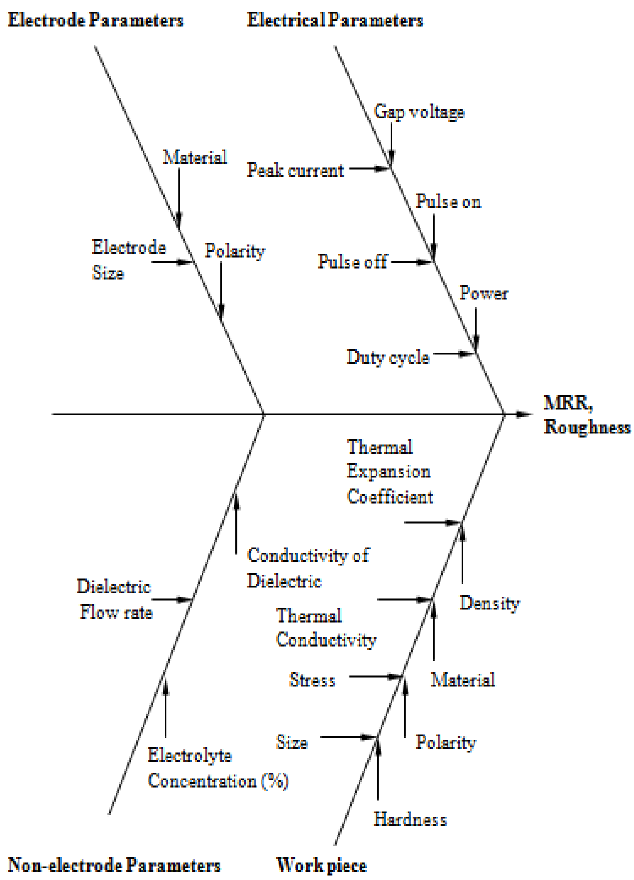

Fig.1 Fish bone diagram showing parameters affecting material removal rate (MRR).

The objective of this paper is to study the influence of machining parameters of EDM on Aluminium alloy 2014-T6. The second order mathematical models in terms of machining parameters are developed for MRR prediction using Response Surface Methodology (RSM), Taguchi`s method and artificial neural networking on the basis of experimental results.

Wire Electric discharge machining

In Aluminium alloy 2014-T6 WEDM process the work piece is placed on the fixture table and fixed securely by clamps and bolts. The table moves along X and Y-axis and it is driven by the DC servo motors. Wire electrode usually made of thin copper, brass, molybdenum or tungsten of diameter 0.05-0.30 mm, which transforms electrical energy to thermal energy, is used for cutting materials. The wire is stored and wound on a wire drum which can rotate at1500rpm. The wire is continuously fed from wire drum which moves through the work piece and is supported under tension between a pair of wire guides located at the opposite sides of the work piece. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining [6]. Also the work piece and the wire electrode (tool) are separated by a thin film of dielectric fluid that is continuously fed to the machining zone to flush away the eroded particles. The movement of table is controlled numerically to achieve the desired three-dimensional shape and accuracy of the work piece [7].

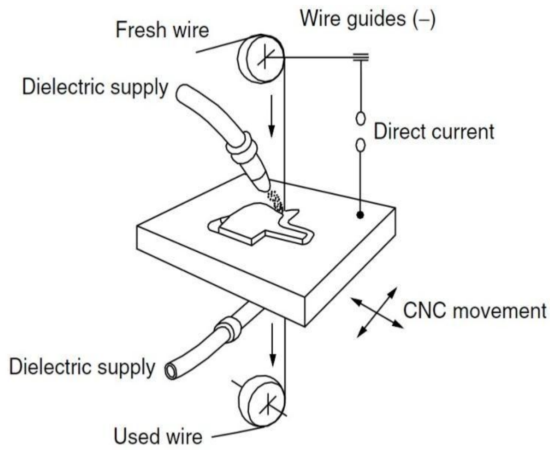

Fig.2 Wire electrical discharge machine

2. LITERATURE REVIEW

The literature review focuses on study of related journal papers and articles. The literature covers the wire electrical discharge machining process related to input parameters and machining parameters on output response parameters using optimization techniques.

D. Sudhakara et al. [1] did experimental work on advancing the wire electrical discharge machine process parameters for the normal surface roughness (Ra) acquired in machining of VANADIS- 4e (Powder metallurgical cold worked Tool steel). The Machining analysis was performed at WEDM machine using 0.25 mm wire as electrode material on p/m cold worked tool steel. Taguchi L27 orthogonal array (OA) was used to outline of trial. Ideal methodology parameters were resolved utilizing the signal- to-noise (S/N) proportion which was computed for Ra as per "the- smaller- the-better" approach. The methodology parameters of WEDM procedure were pulse on time (ON), pulse off time (OFF), servo voltage (SV), peak current (IP), wire tension (WT) and water pressure (WP). The impacts of the methodology parameters on surface roughness were assessed by the examination of change (ANOVA). The most essential associations, that impact surface roughness of machined surfaces, are between the pulse on time (ON) and pulse on time(ON), pulse off time(OFF) and Peak current(IP), and between pulse on time(on) and Peak current(IP). The ideal estimation of surface roughness is anticipated at the ideal levels of noteworthy as Pulse on time (A1), pulse off time, peak current and spark gap set voltage and wire tension. The effects of machining parameters on surface roughness with wire electric discharge machining process has been studied with the aim of minimization of surface roughness utilizing Taguchi's design. The effects of the process parameters viz. pulse on time, pulse off time, peak current, spark gap set voltage, wire tension and water pressure on replication characteristics cutting rate. The optimal sets of process parameters were obtained for diverse performance measures using Taguchi's design of experiment methodology.

Rao et al. [2] observed experimental investigation & optimization of Wire EDM parameters for surface roughness, MRR and white layer in machining of Aluminium alloy by using input parameters such as pulse on time, pulse off time, peak current, flushing pressure of dielectric .fluid, wire feed rate, wire tension, spark gap voltage. This work is based on analysis of variance (ANOVA). The main aim of the investigation is fulfilled by conducting experiments on Aluminium2014T6 alloy, as this material has converse properties as compared to heavy and other light metals in respect of modulus of rigidity, thermal conducting and melting point. The white layer thickness values obtained at various machining conditions are relatively high when compared to heavy and other light metals.

Anshuman Kumar et al. [3] proposed mathematical modelling of wire electrical discharge machining of super alloy Inconel 718 by the four input parameters such as voltage, peak current, pulse on time, and cutting width. (Kerf). This work has been based on non linear regression analysis, Taguchi method. Thus, it can be concluded that the numerical model would give better prediction of process responses. The results have been compared with those obtained by ANSYS software analysis and experiments.

P. Raju et al. [4] performed experimentation on 316 L Stainless steel using full factorial experimental design. 316 L stainless steel is being widely used in orthopaedic implants, dental implant and cardiovascular stents in biomedical and engineering applications. The paper presents an investigation on the effect of surface roughness of the most influencing wire EDM parameters pulse on time, peak current , servo voltage and wire tension on 316 L SS material. The results have been compared with those obtained by ANOVA table and also by using regression analysis. By using ANOVA technique it was found that the machining variable pulse on time is a significant factor that affects surface roughness. The optimal parametric combination for good surface roughness as obtained from the signal to noise ratio is pulse on time, peak current, servo voltage and wire tension .Also a mathematical model for surface roughness to the input parameters considered is obtained from regression analysis using Minitab software.

Manjalah et al. [5] (2014) studied the wire electric discharge machining (WEDM) characteristics of TiNi SMA. The experiments were planned as per L27 orthogonal array to minimize the experiments; each experiment was performed under different conditions of pulse duration, pulse off time, servo voltage, flushing pressure and wire speed. A multi-response optimization method using Taguchi design with utility concept has been proposed for simultaneous optimization. The analysis of means (ANOM) and ANOVA on signal to noise (S/N) ratio were performed for determining the optimal parameter levels. It was found that the flushing pressure and wire speed for simultaneously minimizing the surface roughness and maximizing the material removal rate.

Hewidy et al. [6] (2005) studied the observation made by the researchers on machining parameters of WEDM on Inconel 601 material such as peak current, duty factor, wire tension and water pressure on the metal removal rate, wear ratio and surface roughness. This work has been based on the response surface methodology (RSM). There was an increase in Surface roughness with the increase of peak current and decrease with the increase of duty factor and wire tension.

Shandilya et al. [7] (2012)- the study has been made to optimize the process parameters during machining of SiCp /2014-T6 Al metal matrix composite (MMC) by wire electrical discharge machining using response surface methodology. Four input process parameters of WEDM (namely servo voltage (V), pulse-on time (Ton), pulse-off time (Toff) and wire feed rate (WF)) were chosen as variables to study the process performance in terms of cutting width (kerf). The fine surface finish was obtained when machining was done at a combination of lower levels of input process parameters.

Ugrasen et al. [8] (2014) - the study was carried out on the three responses namely accuracy, surface roughness, volumetric material removal rate for each experiment. Based on this analysis, process parameters are optimized. Analysis variance (ANOVA) is performed to determine the relative magnitude of each factor on the objective function. Estimation and comparison of responses was done using artificial neural network. The predicted response variables of 70% training set correlates well with the measured response variables.

Ravindranadh et al. [9] (2015)- a comparative study of wire electrical discharge machining of armour materials such as aluminium alloy 7017 and rolled homogeneous armour (RHA) steel using Buckingham pi theorem to model the input variables and thermo-physical characteristics of WEDM on material removal rate (MRR) and surface roughness (Ra) of Al 7017 and RHA steel. The parameters of the model such as pulse-on time, flushing pressure, input power, thermal diffusivity and latent heat of vaporization have been determined through design of experiment methodology. The rise in pulse-on time improves in MRR and surface finish.

F. Vogeler et al. [10] (2016) proposed the effect of wire EDM processing on the flexural strength of large scale ZrO2-TiN. Technical ceramics are generally used in high demanding applications, e.g.: Zirconia (ZrO2) has excellent fracture toughness but it is difficult to machine into complex shapes. Electrical Discharge Machining is a valid option for hard materials, though this requires an electro conductive work piece. In the presented work a large scale ZrO2 blank with a conductive secondary TiN phase is processed by Wire-EDM with different finishing regimes. The input parameters such as pulse on time, peak current, spark gap voltage were used. The effect of flexural strength was calculated using mathematical models.This research shows that there is not a one-to-one correlation between surface roughness, surface integrity and as a consequence flexural strength. When mechanical requirements have priority over surface finishing, it is better not to rely on the surface roughness but examine the surface and sub-surface integrity.

Srinivasa et al. [11] (2014) -to study the effect of wire EDM parameters on aluminium alloy and also the parametric analysis of wire EDM parameters by Taguchi method on surface roughness (SR) and material removal rate (MRR). The parameters pulse on time, peak current and spark gap voltage have shown significant effect on both SR and MRR but differ in optimum levels.

Chen et al. [12] (2010) the study analysed variation of cutting velocity and work piece surface finish depending on wire electrical discharge machining process parameters during manufacture of pure tungsten profiles. A method integrating back-propagation neural network (BPNN) and simulated annealing algorithm (SAA) is proposed to determine an optimal parameter setting of the WEDM process. The BPNN is utilized successfully to predict cutting velocity, roughness average and roughness maximum properties for WEDM process during manufacture of pure tungsten profiles.

A. Caggiano et al. [13] did experiments on advanced sensor signal feature extraction for wire EDM process monitoring. WEDM is investigated in the perspective of zero-defect manufacturing with the scope to detect anomalous process conditions leading to typical defects generated during WEDM, i.e. the occurrence of lines and marks on the resulting work piece surface. A multiple sensor monitoring system is employed to acquire high sampling rate sensorial data relative to signals of voltage and current in the gap between work piece and wire electrode. An advanced signal processing methodology is implemented to extract and select the most relevant features useful to identify the undesired process conditions through a cognitive pattern recognition paradigm. An advanced signal processing methodology based on sensor fusion approach was applied to the voltage and current signals to implement a pulse discriminating methodology and extract a number of sensor signal features with the aim to realize WEDM process analysis and control through the identification of the critical machining conditions responsible for surface defects. The extracted features were used to construct sensor fusion pattern vectors to be fed as input to supervised Neural Network (NN) paradigms in order to find correlations between signal features and work piece surface quality.

R. Bobbili et al. [14] – His study was carried out on modelling and analysis of material removal rate and surface roughness in wire-cut EDM of armour materials such as aluminum alloy 7017 and Rolled Homogeneous Armour (RHA) steel using Buckingham pi theorem to model the input variables and thermo-physical characteristics of WEDM on material removal rate and surface roughness (Ra) of Al 7017 and RHA steel. The parameters of the model such as pulse-on time, flushing pressure, input power, thermal diffusivity and latent heat of vaporization have been determined through design of experiment methodology. Wear rate of brass wire increases with increase in input energy in machining Al 7017. The dependence of thermo-physical properties and machining variables on mechanism of MRR and Ra has been described by performing scanning electron microscope (SEM) study. The rise in pulse-on time from 0.85ms to 1.25ms causes improvement in MRR and deterioration of surface finish. The machined surface has revealed that craters are found on the machined surface. The propensity of formation of craters increases during WEDM with a higher current and larger pulse-on time.

S. Tilekar et al. [15] studied the effect of process parameters on surface roughness and kerf width of aluminium and mild steel are investigated and single objective Taguchi method is used for process parameter optimization. For experimentation spark on time, spark off time, input current and wire feed rate are used as input parameters. Surface roughness and kerf width are measured by using surface profilemeter and optimal microscope respectively. ANOVA shows that the spark on time and the input current have statistically significant effect in case of aluminium and mild steel respectively.

Y. B. Guo et al. [16] studied super alloys such as Inconel 718 is widely used in turbo-machinery industry due to their outstanding mechanical properties. Inconel alloys are very difficult to machine using conventional mechanical processes like broaching, milling or grinding. Wire Electrical Discharge Machining (W-EDM) is an alternative competitive process to manufacture complex Inconel part geometries. However surface integrity of W-EDM Inconel components is poorly understood. This study presents the characteristics of surface integrity vs. discharge energy in W-EDM of Inconel 718. The results show that the EDM surface topography shows dominant coral reef microstructures at high discharge energy, while random micro voids are dominant at low discharge energy. Surface roughness is equivalent for parallel and perpendicular wire directions, and average roughness can be significantly reduced for low discharge energy. The thick white layers are predominantly discontinuous and are non-uniform at relatively high discharge energy. Micro voids are confined within the thick white layers and no micro cracks were found in the subsurface. The thin white layers by trim cut at low discharge energy become more continuous, uniform, and are free of micro voids. Dramatic reduction is observed in micro hardness due to thermal degradation.

By using Wire electrical discharge machining process experimental work done to optimized the process with input parameters such as pulse on time ,pulse off time, servo voltage, peak current, wire tension, water pressure, flushing pressure of dielectric fluid, wire feed rate, spark gap voltage, cutting width (kerf),pulse duration, wire speed, duty factor, bed speed, open gap voltage.. From literature review it has been observed that work piece material is used for process Alloy steel of different grades EN8, EN24, EN31, OHNS die steel, 316 L stainless steel, mild steel, aluminium alloy T6 ,7017,2014 T6, pure tungsten, steel, Inconel 601, Al-Mg-Si based alloy, ZrO2-TiN based alloys, TiNi shape memory alloys, super alloy Inconel 718, SiCp/2014-T6 Al metal matrix composite ,nickel based super alloys for different conditions with different dimensions. Dielectric fluids used are distilled water, deionised water, kerosene, demineralised water, hydrocarbon oil and distilled water. Taguchi Optimization method with L9, L18, and L24 array is used for experimentation and ANOVA for analysis. Also neural network technique is used for process optimization. For optimum output parameter experimentation was done with different input characteristics.

From literature review gaps are found -for optimization limited method of design of experiment (DOE) used for wire electrical discharge machining process with limited process variables like time required for cutting certain shape or size is more, the flushing of dielectric fluid was not proper and it was affecting surface roughness and accuracy of the die material, feed, cutting speed for optimum output surface roughness and material removal rate.

3. SUMMARY OF LITERATURE REVIEW

From above literature review, it has been observed that optimum surface finish and material removal rate obtained with optimum wire electric discharge machining process conditions. Taguchi method used for experiment is best to optimize quality characteristics. ANOVA is best analysis of variance. For analysis of input parameters we can be apply RSM method, ANN method, SEO method of optimization. Also work piece material such as316 L stainless steel, mild steel, aluminium alloy T6, 7017, 2014 T6, pure tungsten, steel, Inconel 601, Al-Mg-Si based alloy, ZrO2-TiN based alloys, TiNi shape memory alloys, super alloy Inconel 718, SiCp/2014-T6 Al metal matrix composite ,nickel based super alloys can be used as work piece material. Copper, Brass, Molybdenum, Zinc and Graphite coated wires can be used as wire electrode for machining the work piece.

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