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Effects of Process Parameters on Machining Characteristics using WEDM of Inconel 625: A Review

Niteen P. Tippe[1],
[1]M.E. Student,
KIT'S College of Engineering,
Kolhapur-416234, Maharashtra, India

S. M. Pise[2],
[2]Associate Professor,
Head of Department of Production Engineering,
K.I.T.'s College of Engineering,
Kolhapur-416234, Maharashtra, India

B. S. Kamble[3]
[3]Assistant Professor,
Department of Production Engineering,
K.I.T.'s College of Engineering,
Kolhapur-416234, Maharashtra, India

***Abstract* - With the increasing demands of high and accurate surface finish and machining of complex shape geometries, conventional machining process are being replaced by non-traditional machining processes. Wire EDM is non-traditional machining processes and it is used to manufacture intricate shapes with great accuracy and good surface roughness. Because of large number of process parameters and response characteristics, lots of researchers have attempted to optimize the process. This paper reviews the research trends in relation between different process parameters such as Pulse ON Time, Pulse OFF Time, Wire Tension and Peak Current and different performance measures including Surface roughness (Ra), Material removal rate (MRR) and Kerf width (KW).**

Keywords Wire Electrical Discharge Machining, Process parameters, Monitoring, Process control, Optimization

INTRODUCTION

One of the important non-traditional machining processes is Wire Electrical Discharge Machine (WEDM), used for machining difficult to machine materials like composites and inter-metallic materials. Wire Electrical Discharge Machine (WEDM) has been an important manufacturing process for the mould, tool, automobiles and die industries. Due to the ability to make complex shape and machining of hard material with Wire Electrical Discharge Machine (WEDM), its use is increasing.

In Mechanical Industry, the demands for alloy materials having high toughness, hardness and impact resistance are increasing. Some materials are difficult to be machined by traditional machining methods. So, non-traditional machining methods including ultrasonic machining, electrochemical machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials. WEDM is popular in all conventional electrical discharging machines (EDM) process, which used a wire electrode to initialize the sparking process. Wire Electrical Discharge Machine (WEDM) process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, conductive ceramics, alloy steel and aerospace materials can be machined irrespective to their toughness and hardness. Furthermore, Wire Electrical Discharge Machine (WEDM) is capable of producing a fine, precise, wear resistant surface and corrosion. A wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which has capacity to achieve very small corner radii. There is no direct contact between the wire and the work piece, eliminating the mechanical stresses during machining. The Wire Electrical Discharge Machining (WEDM) is a good established machining option for manufacturing geometrically complex or hard material parts that are difficult-to-machine by conventional machining processes. Wire-EDM process consists of number of machine setting parameters such as applied ignition pulse current, voltage, pulse duration, range of speed variation, pulse off time, servo-control reference mean voltage, wire speed, wire tension (WT), and injection pressure. The material of work piece and its height (H) affects on the process. All these parameters affects on surface finish and cutting speed to varying degree. It is also involves complex physical and chemical process including cooling and heating.

The Wire Electrical Discharge Machine (WEDM) machine tool has one main worktable for work piece mounting an auxiliary table and wire feed mechanism. The movements of main table call axis X and Y. The wire feed mechanism consist of wire feeder which continuously fed wire along work table. The wire tension mechanism provides tension in wire and let it in straight position. The wire is fed in few possible speeds as meter per minute. Two wire guides located at the opposite sides of the work piece. The lower wire guide is stationary where as the upper wire guide, supported by the auxiliary table. The wire is connected to negative charge and work piece is connected to positive charge. Now series of electrical pulses generated by the pulse generator unit is applied between the work piece and the wire electrode so the spark is occurs. The material is removed from work piece by electro-erosion. The feed is given to the

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work table by servo motor but the wire guide remains stationary. Generally CNC controller is used here. To let out the removed material from work area, during the cutting operation continuous flashing water is applied. It is called dielectric fluid and continuously filtered to maintain its conductivity. To achieve taper cutting, the upper table is tilted in U-V direction. With combination of X-Y movement and U-V movement desire taper is produced. Wire Electrical Discharge Machine (WEDM) has certain advantageous characteristics,

- Hard material to very close tolerances
- Tapered holes may be produced.
- Very fine holes can be produced
- A good surface finish can be obtained

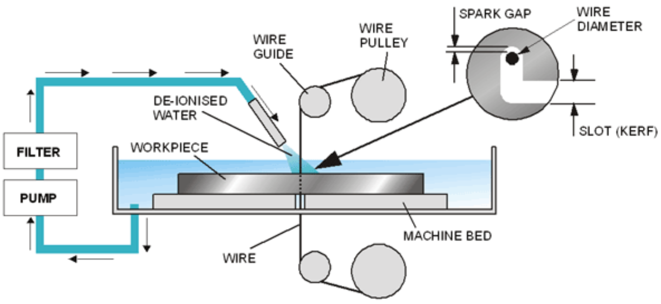

Figure 1 – Process of WEDM

Literature Review

A literature review of the recently published research work on Wire EDM is carried out to understand the research issues involved and is presented here,

Mahapatra and Patnaik [1] studied optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method, Wire electrical discharge machining (WEDM) is extensively used in machining of conductive materials. Rough cutting operation in Wire EDM is treated as a challenging one because improvement of more than one machining performance measures viz. Metal removal rate (MRR), Surface finish (SF) and cutting width (kerf) are try to obtain a precision work. Using Taguchi parameter design, significant machining parameters affecting the performance measures are identified as discharge current, pulse duration, pulse frequency, wire speed, wire tension (WT), and dielectric flow. In this study, the relationship between control factors and responses like Material Removal Rate, Surface Finish and kerf was established by means of nonlinear regression analysis, resulting in a valid mathematical model. Finally, optimum values, was employed to optimize the wire electrical discharge machining process with multiple objectives. From this, WEDM process parameters can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously.

Prajapati and Patel [2] evaluated the effect of pulse On time, pulse Off time, voltage, wire feed and wire tension on Material Removal Rate, Surface Roughness, kerf and gap current in Wire EDM. A experiments have been performed on AISI A2 tool steel in the form of a square bar. Analysis of data optimization and performance is done by Response Surface Methodology (RSM). It is concluded that for cutting rate and surface roughness, the pulse ON and pulse OFF time is most significant. The spark gape set voltage is significant for kerf.

Sivakiran et al. [3] evaluated the effects of various machining parameters Pulse on, Pulse off, Bed speed and Current on metal removal Rate (MRR). From linear regression the relationship between control parameters and Output parameter is developed. Taguchi's L16 Orthogonal Array designs have been used on EN-31 tool steel to achieve maximum metal removal rate. The results obtained are analysed using S/N Ratios, Response table and Response Graphs with the help of Minitab software. In this experimental results are analyzed and Regression equation is developed to predict the metal removal rate and graphs. The better Parameter setting is Pulse on 24µsec, pulse off 6µsec, Bed speed 35µm/s and Current to obtain maximum metal removal rate. With the help of Regression analysis the MRR with 6.77% error is predicted.

Subrahmanyam and Sarcar [4] evaluated the optimized results of process parameters of Wire Electrical Discharge Machining (WEDM) of a work-piece in this paper. For this work, H13 hot die steel is used as the work-piece. Multiple responses of the two parameters Material Removal Rate (MRR) and Surface Roughness (Ra) is identified with the help of Grey-Taguchi Method. Experiments were conducted by considering input parameters T_{ON}, T_{OFF}, Peak Current (IP), Spark gap Voltage (SV), Wire tension (WT), Wire Feed rate (WF), Servo Feed (SF), Flushing pressure of dielectric fluid (WP). Three levels of experiments were obtained. The data related to each response of surface roughness and Material Removal Rate (MRR) is measured for every experiment run. Thus, it can be concluded that the Grey-Taguchi Method, is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process, when using the multiple performance characteristics such as MRR (Material Removal Rate), Surface Roughness for machining the H13 material. A Mathematical relations between the machining parameters and performance characteristics established by the regression analysis method. The established mathematical models can be used in estimating the material removal rate, surface roughness without conducting experiments.

Singh et al. [5] investigated experimentally of Wire EDM to Optimize Dimensional Deviation of EN8 Steel through Taguchi's Technique, Output parameter which is to be optimized is dimensional deviation and input parameters are wire feed, pulse off time and servo voltage. The Taguchi method is used to optimize the parameter. 'L18' orthogonal array is used for statistical analysis. MINITAB-17 software is used to get optimum values for the test and a confirmation experiment was done for validating the results. From the conclusion increasing servo voltage decreases dimensional deviation so that servo voltage has the greatest effect on dimensional deviation.

Atul J. Patel and Prof. Satyam P Patel [6] used Taguchi L9 orthogonal array to find out effects on AISI 304 Stainless Steel. Input parameters such as pulse On-Off time, wire tension and input power have been used to evaluate their effects on Surface Roughness and Material Removal Rate. Mathematical relations between input parameters and performance characteristics were established by the linear regression analysis method by using MINITAB software. It concluded that Pulse on time, Input power, pulse off time and wire tension significantly effects on surface roughness and Material removal rate.

Durairaj et al. [7] studied Analysis of Process Parameters in wire electrical discharge machining (WEDM) with Stainless Steel using Multi Objective Grey Relational Grade and Single Objective Taguchi Method. This paper results the Grey relational theory and Taguchi optimization technique, optimize the input parameters in Wire EDM for SS304. The objective of optimization is to get the minimum kerf width and the best surface quality. In this stainless steel 304 is used as a work piece, tool used as a brass wire of 0.25 mm diameter and distilled water is used as dielectric fluid. For experimentation Taguchi's L16, orthogonal array is used. The input parameters are pulse on time, pulse off time, wire feed, and gap voltage. Fixed parameters are Dielectric fluid pressure, wire tension, wire speed, resistance and cutting length. For every experiment surface roughness and kerf width was determined by using video measuring system and contact type surf coder. By using multi objective optimization technique grey relational theory, the optimal value is obtained for kerf width and surface roughness. By using Taguchi optimization technique, optimized value is obtained separately.

Sharma et al. [8] evaluated the wire electrical discharge machining (WEDM) performance characteristics of Inconel 706. The effect of various input parameters such as servo voltage, pulse on time, pulse off time, servo feed, wire feed and flushing pressure on WEDM performance characteristics, namely, MRR and SR of the Inconel 706 alloy components have been investigated. The proposed experimental plan was based on OFAT approach. Microstructure and surface topography of the machined components have been compared at low and high levels of pulse off time, pulse on time, and servo voltage. The micro hardness and RLT have been examined using the low and high settings of servo voltage and pulse on time. To study the metallurgical changes in the machined surface, EDAX analysis has been carried out.

Dabade and Karidkar [9] studied Analysis of response variables in WEDM of Inconel 718 using Taguchi technique In this paper, researcher analyzed the machining conditions for Material Removal Rate (MRR), Surface Roughness (SR), cutting width (kerf) and Dimensional deviation during wire electrical discharge machining (WEDM) of Inconel 718 using Design of Experimentation (DOE) such as Taguchi methodology. Here L8 Orthogonal Array is used. The experimental analysis is done using Minitab 16 software and it was observed that pulse-on-time is the most influenced parameters for all the response variables such as Material Removal Rate (MRR), Surface Roughness (SR), cutting width (kerf) and Dimensional deviation at 95 % confidence level, with contributions of 54.32 %, 58.42 %, 83.21 % and 36.11 % respectively. Also, peak current was observed to be next influenced for kerf and dimensional deviation where as for Material Removal Rate (MRR), Surface Roughness (SR). Servo voltage was observed the next significant parameter.

Kashid et al. [10] investigated the Effect of Process Parameters on Material Removal Rate in Wire-cut Electrical Discharge Machining of Steel Grade EN 9. In this paper, the Taguchi method is proposed for wire electrical discharge machining (WEDM) of steel grade EN 9 component. Pulse on-time, Pulse off-time and wire feed these process parameters are selected for this investigation. The experimentation is carried out by using Taguchi's L9 orthogonal array. Signal to Noise ratios of the Material removal rate for all experiments are calculated. The results are analyzed using analysis of variance (ANOVA) and response graphs.

Manikandan et al. **[11]** studied Optimized Machining Process Parameters in Wire Cut EDM. In this research paper, the performance parameters of WEDM are founded on the basis of Material Removal Rate (MRR), Surface Roughness (SR) and KERF Width. The machining parameters of EDM which influenced on the performance parameters are pulse on time, pulse off time, discharge current, arc gap, flushing pressure, servo voltage and wire tension. Taguchi design of experiments is used to conduct experiments by varying the parameters servo voltage, pulse on time and pulse off time. The process performance is measured in terms of Material Removal Rate (MRR), KERF Width and Surface Roughness (Ra). In this paper, WEDM experiment using 0.25 mm diameter copper wire (Zinc coated) & EN-31 tool Steel work piece has been done for optimizing MRR, KERF width, Surface finish and reducing cost of manufacturing. By using multi objective optimization technique grey relational theory, the optimize value is obtained for MRR, surface roughness and KERF width.

Patil and Waghmare [12] studied Optimization of Process Parameters in Wire-EDM Using Response Surface Methodology (RSM). In this paper, Response Surface Methodology approach for maximize the Material Removal Rate (MRR) in wire electrical discharge machining. The investigated machining parameters were wire tension, pulse on time and peak current. Machining was carried on AISI D2 cold work steel, which is widely used in die and mold making industries. The experiments were designed based on response surface design method. After the experimentation, the effect of the parameters on Material Removal Rate (MRR) was determined by analysis of variance (ANOVA). Regression analysis was done and a second order mathematical model was fitted for Material Removal Rate (MRR) considering the parameters and their significant interactions. Optimization was carried using desirability approach and confirmation experiments were performed.

Nagaraja et al. [13] studied Optimization of Parameter for Metal Matrix Composite in Wire EDM. In this paper, an investigation on the optimization of machining parameters in

WEDM of bronze-alumina MMC. The main aim is to find the optimum cutting parameters to achieve a minimum Surface roughness and maximum material removal rate (MRR). The cutting parameters considered are, pulse on time, pulse off time and wire feed rate. The optimum values for cutting parameters were determined by using Taguchi experimental design method. An L9 orthogonal array was selected. Signal to Noise ratio and analysis of variance (ANOVA) was used to analyze the effect of the machining parameters on surface roughness and to identify the optimum cutting parameters. The contribution of each cutting parameters towards the surface roughness and MRR is also identified. The study shows that the Taguchi method is suitable to solve the stated problem with minimum number of trails as compared.

Chockalingam et al. [14] studied Optimization Studies in CNC Wire Cut EDM: A Review. This paper reviews the research trends in relation between number of process parameters and different performance measures including Surface roughness (Ra), Dimensional deviation (DD), material removal rate (MRR), kerf width (KW) and wire wear ratio (WWR). In addition, this paper highlights various optimization methods and discusses their role in CNC WEDM process.

CONCLUSION

Many investigations had done on WEDM process. Study of process parameters such as Pulse-on time, Pulse-off time, Peak current, servo voltage, Wire tension, Wire feed, Servo feed, Fluid pressure and performance measures as surface roughness (SR), material removal rate (MRR), kerf width, Dimensional deviation is carried out more by researchers.

From the literature review it is observed that mostly combinations of process parameters like Pulse-on time, Pulse-off time, Peak current, Wire tension, servo voltage, Wire feed, Servo feed and performance measures as surface roughness (SR), material removal rate (MRR), kerf width, Dimensional deviation are investigated. Pulse on time, pulse off time and wire tension significantly effects on SR & MRR. Surface roughness depends on pulse on time and servo voltage, Machining voltage. Pulse duration determines the Kerf width. Dimensional deviation is influenced by pulse duration and wire tension. Servo voltage has the greatest effect on Dimensional deviation. So it is important to find the optimum conditions for process parameters to give better quality of Surface Roughness. It was found that many researchers have employed different optimization techniques like Taguchi method, Grey Relational Theory, Response Surface Methodology, Regression analysis to find out Maximum MRR, Minimum SR and Minimum kerf width for WEDM operation. But less work has been reported on Multi-objective optimization of WEDM process. Also very little work has been reported on Inconel 625 material. So, more work is required to be done in this area.

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