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Optimization of Wire-EDM Process Parameters on Machining Die Steel DC53 using Taguchi Method with Grey Relational Analysis – A Review

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Abstract: Unconventional machining processes are used where traditional machining processes are unable to meet the necessary requirements efficiently and economically. Wire Electrical Discharge Machining (WEDM) is one such machi:ning process. It is widely used in machining of conductive materials when precision is of primary significance. This paper presents the literature review of previous work done by researchers on WEDM for optimization using different techniques like improving performance characteristics, optimizing process variables, monitoring and controlling the sparking process, simplifying the wire design and improving spark efficiency.

Keywords* *Unconventional machining, WEDM, Optimization

I. INTRODUCTION

A. Wedm

Wire Electric Discharge Machining (WEDM) is a specialized thermal non-traditional process of material removal from electrically conductive materials to produce parts with intricate shapes and profiles. It is capable of accurately machining parts with varying hardness or complex shapes which have sharp edges that are very difficult to be machined by the main stream machining processes. It utilizes a continuously travelling wire electrode made of Cu, brass or tungsten of diameter 0.05 - 0.3mm, capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. This process is done by using a series of spark erosion. These sparks are produced between the work piece and a wire electrode (usually less than 0.30 mm diameter) separated by a dielectric fluid and erodes the work piece to produce complex two and three dimensional shapes according to a numerically controlled pre-programmed path. The sparks produce heat and melt the work piece surface to form debris which is then flushed away by dielectric fluid. De-ionized water is used as the dielectric fluid as it is the purest form of water and it acts as an insulator. Normal tap water contains minerals which may be too conductive for Wire EDM, in order to control the water conductivity; water is de-ionized by passing it through a resin tank which eliminates the conductive elements of water. This de-ionized water is circulated with the help of a pump. As the machining operation is performed, conductivity of water rises and it is again re-circulated through the resin tank. The purpose of de-ionized water is to stabilize the spark erosion path and to act as the dielectric medium which is forced into the cutting gap to flush out the eroded metal. There is virtually no cutting force on the part of the machine because the wire electrode and work piece never make contact. A WEDM schematic is shown in Fig.1.

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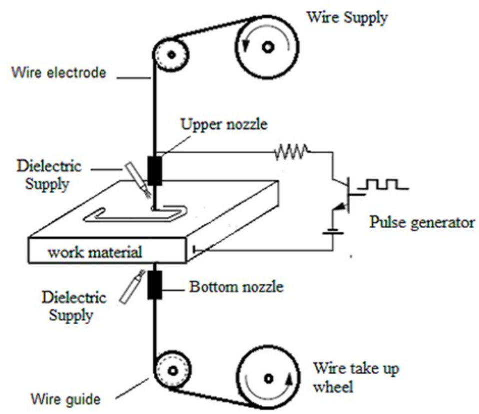

Fig.1 Schematic Diagram of WEDM (Shinde & Shivade, 2014)[18]

B. Importance of WEDM in Industry

The development of new advanced engineering materials and the need to meet demand for precise and flexible prototype and low volume production of components have made wire electrical discharge machining and important manufacturing process. The degree of accuracy of work piece dimensions obtainable and the fine surface finish make WEDM particularly valuable for applications involving manufacture of stamping dies, extrusion dies and prototype parts. Its broad capabilities have allowed it to encompass the production, aerospace and automotive industries and virtually all areas of conductive material machining. This is because WEDM provides the best alternative or sometimes the only alternative for machining conductive, exotic, high strength and temperature resistive materials, conductive engineering ceramics with the scope of generating intricate shapes and profiles. WEDM is being used to machine a wide variety of miniature and micro-parts from metals, alloys, sintered materials, cemented carbides, ceramics and silicon. Without WEDM, the fabrication of precision work piece would require many hours of manual grinding and polishing. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface. WEDM has tremendous potential in its applicability in the present day metal cutting industry for achieving a considerable dimensional accuracy, surface finish and contour generation features of products or parts. Moreover, the cost of wire contributes only 10% of operating cost of WEDM process. The difficulties encountered in the die sinking EDM are avoided by WEDM, because complex design tool is replaced by moving conductive wire and relative movement of wire guides.

C. Taguchi's Philosophy

The Taguchi method was developed by Dr. Genichi Taguchi of Japan. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal array to organize the parameters affecting the process and the levels at which they should be varies. Instead to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of a variable (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

D. Grey Relational Analysis

In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. The theory of grey system which was proposed by Deng [Deng 1989; Deng 1982][1][2] takes use of grey relational generation and calculates the grey relational coefficient to handle the uncertain systematic problem under the status of only partial known information. Therefore, the grey relational coefficient can express the relationship between the desired and actual experimental results, and the grey relational grade is simultaneously computed corresponding to each performance characteristic [Zhu *et al.* 1996; Tan *et al.* 1998]. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristics of multiple response process depend on the calculated grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation, where the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade.

II. LITERATURE SURVEY

Literature survey/review provides the scope for the present study. Literature review should contain academic journals, government reports, books, the earlier research studies relevant to the research problem. Literature review provides the data to narrow the problem itself as well as the techniques that might be used. This would also help a researcher to know if there are certain gaps in the research work. Spedding and Wang [1997] made an attempt at modelling the process through Response Surface Methodology and ArtificialNeural Networks. Wire electrical discharge machining (WEDM) technology has been used widely in production, aerospace/aircraft, medical and virtually all areas of conductive material machining. Its complexity and stochastic nature have stimulated numerous attempts to model it accurately. A response surface model based on a central composite rotatable experimental design, and a 4-16-3 size back-propagation neural network has been developed. The pulse-width, the time between two pulses, the wire mechanical tension and the injection set-point are selected as the factors (input parameters); whilst the cutting speed, the surface roughness and the surface waviness are the responses (output parameters). The two models are compared for goodness of fit. Verification experiments have been carried out to check the validity of the developed models. It is concluded that both models provide accurate results for the process.[3] Huang *et al.* [1999] made an attempt to unveil the influence of the machining parameters (pulse-on time, pulse-off time, table feed-rate, flushing pressure, distance between wire periphery and work piece surface) on the machining performance of WEDM in roughness cutting operations. The gap width, the surface roughness and the white layer depth of the machined work piece surface are measured and evaluated. Based on the Taguchi quality design method and numerical analysis, it is found that the pulse-on time and the distance between the wire periphery and the work piece surface are two significant factors affecting the machining performance. Mathematical models relating machining parameters and performance are established by regression and non-linear programming using the Feasible-direction algorithm to obtain the optimal machining parameters. A strategy of optimal multi-cut WEDM process planning from rough to finish cutting operations, including the number of machining operations and their corresponding machining-parameters setting for each operation, has been proposed. Experimental results show that the proposed approach can achieve better performance than that achieved by a well-skilled operator. A better surface quality and dimensional accuracy value can be obtained in less machining time.[4] Puri and Bhattacharya [2003] carried out an extensive study of wire lag phenomenon in WEDM and established the trend of variation of geometrical inaccuracy caused due to wire lag with various machine control parameters. In this research study, all the machine control parameters are considered simultaneously for machining operation which comprised a rough cut followed by a trim cut. The objective of study was to carry out an experimental investigation based on the Taguchi method involving thirteen control factors for given machining criteria, such as average cutting speed, surface roughness characteristics and geometrical inaccuracy caused due to wire lag.[5] Cogun and Tosun [2004] carried out an investigation on the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in WEDM operations. The experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. The settings of machining parameters were determined by using Taguchi experimental design method. The level of importance of the machining parameters on the cutting kerf and MRR is determined by using analysis of variance (ANOVA). The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (*S*/*N*) ratio. The variation of kerf and MRR with machining parameters is mathematically modeled by using regression analysis method. The optimal search for machining parameters for the objective of minimum kerf together with maximum MRR is performed by using the established mathematical models.[6] Kuriakose and Shunmugam [2005] developed a multiple regression model to represent relationship between input and output variables and a multi-objective optimization method based on a Non-Dominated Sorting Genetic Algorithm (NSGA) was used to optimize WEDM process. WEDM is one of the important non-traditional machining processes, which is used for machining of difficult-to-machine materials and intricate profiles. Being a complex process, it is very difficult to determine optimal parameters for improving cutting performance. Cutting velocity and surface roughness are most important output parameters, which decide the cutting performance. There is no single optimal combination of cutting parameters, as their influences on the cutting velocity and the surface roughness are opposite in nature. A non-dominated solution set has been obtained and reported.[7] Mahapatra and Patnaik [2006] described the development of a model and its application to optimize WEDM machining parameters. This paper outlines the development of a model and its application to optimize WEDM machining parameters. Experiments are conducted to test the model and satisfactory results are obtained. The methodology described here is expected to be highly beneficial to manufacturing industries, and also other areas such as aerospace, automobile and tool making industries.[8] Kanlayasiri and Boonmung [2007] presented an investigation of the effects of machining variables on the surface roughness of WEDMed DC53 die steel. In this study, the machining variables investigated were pulse-peak current, pulse-on time, pulse-off time, and wire tension. Analysis of variance (ANOVA) technique was used to find out the variables affecting the surface roughness. Assumptions of ANOVA were discussed and carefully examined using analysis of residuals. Quantitative testing methods on residual analysis were used in place of the typical qualitative testing techniques. Results from the analysis show that pulse-on time and pulse-peak current are significant variables to the surface roughness of WEDMed DC53 die steel. The surface roughness of the test specimen increases when these two parameters increase. Lastly, a mathematical model was developed using multiple regression method to formulate the pulse-on time and pulse-peak current to the surface roughness. The developed model was validated with a new set of experimental data, and the maximum prediction error of the model was less than 7%.[9] Pandey [2010] has resulted that EDM is most cost effective and precision machining process in recent years. The capacity of machining hard and difficult to machine parts has made EDM as one of the most important machining processes. The contribution Variants of EDM has brought tremendous improvements in the surface finish of machined advanced engineering materials. Powder mixed EDM and Ultrasonic assisted EDM has not only reduces tool wear but also increases material removal rate. Modelling and optimization of various electrical and non electrical parameters in EDM improved in precision machining of work materials The review of the research trends in EDM on rotary EDM, dry EDM machining, EDM with powder additives, Ultrasonic assisted EDM ,WEDM and Micro EDM performances is presented.[10] Kapoor *et al.* [2010] presented a study on different Wire electrodes which are being used in the industry and some high performance electrodes have been observed. It has been investigated that wire electrode contribute directly to cutting speed and dimensional 22 accuracy. Some of the electrodes studied are copper, brass and coated wire electrodes. It has been observed that for different materials different metal wire electrodes are preferred as they offer better response parameters such as better surface roughness, higher MRR etc. Composite wires have replaced zinc coated wires. Wires having higher tensile strength offer breakage resistance and can be obtained at the expense of fracture toughness. Copper clad wires are used for tall work pieces. High performance wires offer better productivity but with certain limitations such as cost, flaking etc., also they cannot be used all WEDM machine.[11] Patil and Brahmankar [2010] investigated electrical and non electrical process parameters for machining metal matrix composite. The metal matrix composite chosen for this experiment is reinforced aluminium matrix composite and wire used is a brass wire of 0.25 mm diameter. Process parameters that have been chosen were reinforcement percentage current, pulse on-time, off time, servo reference voltage, maximum feed speed, wire speed, flushing pressure and wire tension whereas the response parameters were cutting speed surface roughness, and kerf width. Taguchi design methodology has been used to study the effect of performance parameters on the response parameters. It has been observed that WEDM is a good process to machine metal matrix composites and reinforcement percentage current and pulse on time have significant effect on cutting rate, surface roughness, and kerf width.[12] Datta and Mahapatra [2010] proposed a quadratic mathematical model and conducted experiments by taking six WEDM process parameters: discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate. Experiments were carried out on D2 Tool Steel using a Zinc coated Copper wire electrode. The response parameters noticed for each experiment were MRR, Surface Roughness and Kerf. A statistical analysis has been carried for each result and responses have been utilized to fit the quadratic model which represents the above said six parameters. Grey based Taguchi technique has been utilized to evaluate optimal parameter combination to achieve maximum MRR, minimum roughness value and minimum width of cut. It has been found out that for continuous quality improvement Grey based Taguchi method is a very reliable method to predict optimal parameter values and all the parameters involved in the experimentation are independent of each other.[13] Pasam *et al.* [2010] developed a mathematical model by using linear regression analysis in order to present a relationship between control parameters and response parameters. Titanium alloy is chosen as work piece material. Control parameters which have been varied are Ignition pulse current, Short pulse duration, Time between two pulses, Servo speed, Servo reference voltage, Injection pressure, Wire speed and Wire tension and the response parameter studied for the above parameters is surface roughness. Genetic algorithm modeling has been used to optimize the process parameters for surface roughness. Regression coefficient of 0.943 is obtained for surface roughness model by regression analysis and surface roughness of 1.85 μm is obtained with selected optimum control parameters in the WEDM of Ti6Al4V alloy.[14] Kapoor *et al.* [2011] presents the results of the effect of Cryogenic treated brass wire electrode on the surface of an EN-31 steel machined by WEDM. Full factorial experimental design strategy is used in the experimentation. Three process parameters, namely type of wire electrode (untreated and cryogenic treated brass wire electrodes), Pulse width, and wire tension have been considered. The process performance is measured in terms of surface roughness (SR). ANOVA results indicated that all the process parameters have significant effect on SR. Scanning electron microscopy highlighted the important features of WEDMed surfaces with cryogenic treated and untreated brass wire electrode. Surface roughness is improved with cryogenic treated brass wire electrode.[15] Sharma and Khanna [2012] studied the effects of various process parameters of WEDM as pulse width, time between two pulses, maximum feed rate, servo reference mean voltage, short pulse time and wire mechanical tension, have been experimented for optimizing surface roughness while machining cryogenic treated D-3 material. Experimental observations are based on Taguchi's L-27 orthogonal array has been done. Signal to- Noise (S/N) ratio, Analysis of Variance (ANOVA) and various plots are used to find the optimum process parameter with a least surface roughness. The confirmation experiments has been done for validate the results calculated by using taguchi method. It is concluded that pulse width and time between two pulses were significant variables to the surface roughness of wire-EDMed cryogenic treated D-3.[16] Singh and Singh [2012] studied that wear behaviour AISI D3 Die steel in EDM and compare the tool wear rate of cryogenic treated cooper and brass electrode with simple copper and brass electrode on machining of AISI D3 die steel using current setting as 4A and 8A. The electrolyte is used kerosene oil. Copper electrode is best electrode for high material removal rate. But cryogenic treated copper electrode has very low tool wear as compared to cooper electrode.[17] Rao *et al.* [2015] concluded that the influence of parameters like discharge current, job thickness, on the machining criteria such as cutting speed, spark gap, material removal rate are determined. The results are useful in setting the parameters required for quality cuts on HC-HCr die steel. Suitable parameters can be selected for machining with the 0.25mm diameter wire. The mathematical relations developed are much more beneficial for machine settings, to estimate the cutting time, cost of machining and accuracy of cutting for any size of the job within machine range. The maximum error obtained in the calculated values and experimental values are less than 2%.[19]

III. RESULT

After a comprehensive study of the existing literature, it is found that there are a number of gaps in the process of Wire Electrical Discharge Machining. Following are some of the gaps that are observed

A. The effect of machining parameters on Die Steel DC53 alloy steel has not been fully explored using WEDM with brass wire as the wire electrode.
B. Literature review reveals that the researchers have carried out most of the work on WEDM developments, monitoring and control but very limited work has been reported on optimization of the process variables.

IV. CONCLUSION

The work presented here is just an overview of previously done researches and future directions of Wire Electrical Discharge Machining process using different optimization techniques. The conclusions drawn are discussed below.

A. Wire Electrical Discharge Machining (WEDM) process is an unconventional material removal process which is used for cutting intricate shapes, efficiently and economically.
B. The performance of Wire Electrical Discharge Machining process depends on number of process parameters like pulse-on time, pulse-off time, wire feed etc.
C. The responses like material removal rate and surface roughness all are affected by the process parameters.
D. From the above literature, it has been reviewed that different optimization techniques were used for optimization of different WEDM process parameters for different materials.
E. Main objective of this literature survey is to identify different WEDM process parameters, performance characteristics, materials and optimization techniques and to find out some research gap for future research work to become beneficial to industry people.

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