WEDM Development and Optimization of process: A review

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Abstract- Wire electrical discharge machining (WEDM) is a non-conventional machining method used to cut hard to machine material, which are difficult to process by conventional processes. The applications of WEDM are in automobiles, aero-space, medical instruments, tool and die industries. In this research paper the review of WEDM has been explored into development and optimization of process phases.

Keywords – WEDM, Review, Process development, Optimization.

I. INTRODUCTION

Wire Electrical Discharge Machining (Wire-EDM) is an electro thermal production process in which a thin single-strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials. Electrical discharge machining is frequently used to make dies and molds [1, 2]. It has recently become a standard method of producing prototypes and some production parts, particularly in low volume applications.

In the recent years an extensive research has been carried out on WEDM relating to improving performance measures, optimizing the process variables, monitoring and controlling the sparking process, simplifying the wire design and manufacture, improving the sparking efficiency by various researchers. Some of the work related to the present study is discussed in the following paragraphs:

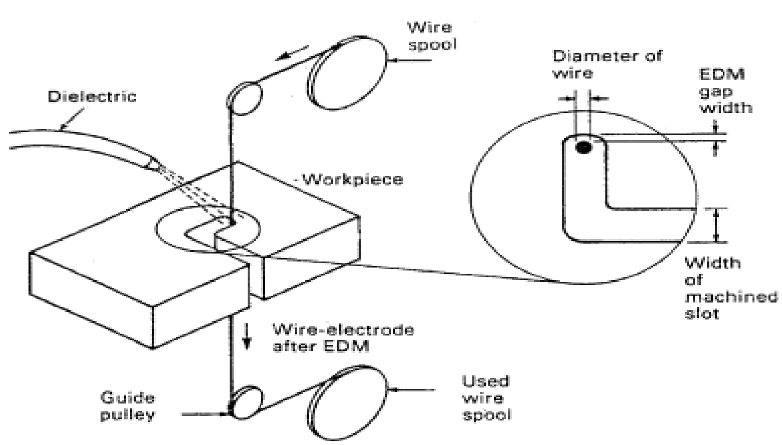

Figure 1: Principle of WEDM

II. MACHINING CHARACTERISTICS EVALUATION

Process Parameters In 1984 P.C.Pandey and S.T. Jilani [3] worked on the machining characteristics of distilled water, tap water and a mixture of 25% tap and 75% distilled water when used as dielectric fluid in EDM are reported. Two different tool materials, brass and copper with positive and negative polarities have been used to machine low carbon steel work-pieces at low current densities. All the experiments have been planned statistically and response surface equations for metal removal rate, relative electrode wear and surface roughness have been obtained. The best machining rates have been achieved with the tap water and a special feature of machining in water was the possibility of achieving zero electrode wear especially when copper tools with negative polarities were used.

In 1991 Williams and Rajurkar [4] observed that the complex and random nature of the erosion process in WEDM requires the application of deterministic as well as stochastic techniques. Surface roughness profiles were studied with a stochastic modeling and analysis methodology to better understand the process mechanism. Scanning electron microscopic (SEM) examination highlighted important features of WED machined surfaces. In 1995 Speeding and Wang [5] modelling the WEDM process through Response Surface Methodology and Artificial Neural Networks. A response surface model based on a central composite rotatable experimental design, and a 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.

J.T. Huang et al. [6] found the role of WEDM in precision manufacturing. To obtain a precise work-piece with good surface quality, some extra repetitive finish cuts along the rough cutting contour are necessary. An attempt has been made to unveil the influence of the machining parameter (pulse-on time, pulse-off time, table feed-rate, flushing pressure, distance between wire periphery and work-piece surface, and machining history) on the machining performance of WEDM in finish cutting operations. Their research shows that the proposed approach can achieve better performance than that achieved by a well-skilled operator. A better surface quality and accurate dimension value can be obtained in less machining time.

Speeding and Wang [7] revealed that WEDM technology has been widely used in conductive material machining. The WEDM process, which is a combination of electro-dynamic, electromagnetic, thermal-dynamic, and hydrodynamic actions, exhibits a complex and stochastic nature. Its performance, in terms of surface finish and machining productivity, is affected by many factors. In this an attempt at optimization of the process parametric combinations by modeling the process using artificial neural networks (ANN) and characterizes the WEDMed surface through time series techniques. Kozak et al. [8] experimented that WEDM of low conductive materials demonstrates that total electrical resistance between the work-piece and wire electrode vary during machining depending upon the clamping position. This change in resistance causes a change in material removal rate (MRR) and average surface roughness that leads to poor quality of products. A technique developed in this work minimizes the change in resistance offered by the work-piece material. A conductive silver coating is applied over the work-piece surface. Due to silver coating, the drop voltage in work-piece material is reduced; thereby decreasing energy loss in work-piece material. It was also observed that conductive silver coating not only minimizes the variation in resistance but also it increases the productivity of the process.

Tosun et al. [9] studied the variation of work-piece surface roughness with varying pulse duration, open circuit voltage, wire speed and dielectric fluid pressure was experimentally investigated in WEDM. Brass wire with 0.25 mm diameter and SAE 4140 steel with 10 mm thickness were used as tool and work-piece materials in the experiments, respectively. It is found experimentally that the increasing pulse duration, open circuit voltage and wire speed, increase the surface roughness whereas the increasing dielectric fluid pressure decreases the surface roughness. The variation of work-piece surface roughness with machining parameters is modelled by using a power function. The level of importance of the machining parameters on the work-piece surface roughness is determined by using analysis of variance (ANOVA). Puertas and Luis [10] experiment on the optimum selection of manufacturing conditions is very important in manufacturing processes as these ones determine surface quality and dimensional precision of the so-obtained parts. Thus, it is necessary to know, in advance, properties relating to surface quality and dimensional precision by means of theoretical models which allow doing some predictions taking into account operation conditions such as gap, dielectric fluid, penetration speed, etc. Manufacturing materials with non-conventional processes such as electrical discharge machining, shows really important aspects to study from the point of view of materials science, heat transmission, mechanics and manufacturing processes optimization. The study is mainly focused on aspects related to surface quality and dimensional precision, which are one of the most important parameters form the point of view of selecting the optimum conditions of processes, as well as economical aspects. Functions making it possible to optimize parameters related to surface quality in such manufacturing processes will be obtained by means of using mathematical models that will allow us to select the optimum manufacturing conditions. S. Sarkar et al. [11] presented an investigation on WEDM of γ-titanium aluminide alloy. An extensive research study has been carried out with an aim to select the optimum cutting condition with an appropriate wire offset setting in order to get the desired surface finish and dimensional accuracy. The process has been modeled using additive model in order to predict the response parameters i.e. cutting speed, surface finish and dimensional deviation as function of different control parameters and the main influencing factors are determined for each given machining criteria. Finally, the optimum parametric setting for different machining situation arising out of customer requirements have been synthesized and reported. El-Taweel et al. [12] reveals that WEDM allowed success in the production of newer materials, especially for the aerospace and medical industries. Using WEDM technology, complicated cuts can be made through difficult-to-machine electrically conductive components. The high degree of the obtainable accuracy and the fine surface quality make WEDM valuable. The right selection of the machining conditions is the most important aspect to take into consideration in processes related to the WEDM of Inconel 601 material. Their work highlights the development of mathematical models for correlating the inter-relationships of various WEDM machining parameters of 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 established based on the response surface methodology (RSM). Shajan Kuriakose and M.S. Shunmugam [13] reported that 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 finish 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 finish are quite the opposite. In their work, a multiple regression model is used to represent relationship between input and output variables and a multi-objective optimization method based on a Non-Dominated Sorting Genetic Algorithm (NSGA) is used to optimize Wire-EDM process. K. Kanlayasiri, S. Boonmung [14] developed cold die steel (DC53) from Daido Steel, Japan. It is an improvement over the familiar cold die steel SKD11. They investigate the effects of machining variables on the surface roughness of wire-EDMed DC53 die steel. Analysis of variance (ANOVA) technique was used to find out the variables affecting the surface roughness. 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. In 2009 Singh and Garg [15] found that the material removal rate (MRR) directly increases with increase in pulse on time and peak current while decreases with increase in pulse off time and servo voltage. They used hot die steel (H-11) as work-piece.

In 2011 Natarajan et al. [16] focuses RSM for the multiple response optimization in micro-endmilling operation to achieve maximum metal removal rate (MRR) and minimum surface roughness. Aluminium block of 60×40×16 mm is used as the workpiece material and carbide endmill cutter of diameter 1 mm as the cutting tool. In 1999 Liao et al. [17] studied the geometry properties of WEDM process in corner cutting. The concept of discharge-angle is introduced, and its mathematical expression is derived by analytical geometry. A model to estimate the metal removal rate (MRR) in geometrical cutting is developed by considering wire deflection with transformed exponential trajectory of wire centre. The computed MRR is compared with measured sparking frequency of the process since they are equivalent to each other for an iso-energy type machine. Both of the discharge-angle and MRR drop drastically to a minimum value depending on the corner angle being cut as the guides arrive at the corner apex, and then recover to the same level of straight-path cutting sluggishly. In 2002 Tosun and Cogun [18] studied the effect of cutting parameter on wire electrode wear experimentally in Wire electric discharge machining. The experiment was conducted under different setting of pulse duration, open circuit voltage, wire speed and dielectric fluid pressure. Brass wire of 0.25mm diameter and AISI 4140 steel of 10 mm thickness were used as tool and work piece. It is found experimentally that increasing the pulse duration and open circuit voltage increase the wire wear ratio (WWR) whereas increasing the speed decreases it. The variation of work-piece material removal rate and average surface roughness also investigated in relation of WWR.

Singh and Khanna [19] worked on cryogenic treated D-3 as a workpiece and brass wire as a tool. Charmills Technologies Robofill 290 was the machine tool used for research work. The planning of experiments was carried by Taguchi technique and L27 orthogonal array was selected. The results show that cutting rate decreases with increase in pulse width, time between two pulses, and servo reference mean voltage. Cutting rate first decreases and then increases with the increase in mechanical tension. Sharma et al. [20] optimized the process parameters for the cutting speed and dimensional deviation for high strength low alloy steel (HSLA) on WEDM. Response surface methodology was used for the modelling and multi-response optimization.

Gupta et al. [21] optimized the machining characteristics for kerf width on WEDM. During the experimentations HSLA steel used as work-piece and brass wire as an electrode. The central composite rotatable design has been used to conduct the experiments. The analysis of results indicates that the spark gap voltage, pulse on time, peak current and pulse off time have a significant effect on kerf width.

III. Process Development

Bhatti and Hashmi [22] worked on the production of complex and intricate shapes can be aided greatly, with additional manipulation facilities for the work-piece and/or the cutting tool in 1992. Their research describes briefly the design and interfacing of such a manipulator, in particular, the problems encountered during this research work. Tests have been carried out using a model material to simulate the WEDM process and components having 3-dimensional external or internal surfaces have been machined. In 1993 Rajurkar and Wang [23] developed WEDM sparking frequency monitor to detect the thermal load for on-line control to prevent the wire from rupture. The wire rupture phenomenon is also analyzed with a thermal model. An extensive experimental investigation has been carried out to determine the process performances such as machining rate and surface finish with overall control parameters of an ED machine. The relationship between the machining rate and surface finish under optimal machine settings has been determined by means of a multi-objective model.

Mishra, Prashad and Banerjee [24] worked on the frequent occurrence of rupture of the wire is one of the most serious production constraints in EDM wire cutting in 1993. The phenomenon restricts the cutting speed, increases the machining time and affects the surface finish and accuracy adversely. The probable causes leading to wire rupture are failure under thermal load, failure through short-circuiting and wire vibration, the most important among these being the thermal load. In their work, a simple computational model is developed which will give the temperature values for varying magnitudes of parameters, viz., input power, pulse-on time, wire velocity and wire diameter. In 1996 Beltrami et al. [25] work deals with a technical realization to improve the WEDM accuracy while cutting at full speed on virtually any contour. The system which is readily available on commercial WEDM is based on the on-line monitoring and control of the wire position by means of an optical sensor. The deviation of the wire position relative to the programmed wire path position is continuously measured and corrections are made during the machine cutting. Compared to conventional wire EDM machines, this technique allows to cut complex shapes, arc paths and contours at much faster cutting speed.

In 1997 Mamalis et al. [26] reported in their research that requirements of the materials used for WEDM electrodes that will lead to the improvement of WEDM performance. Experiments have been conducted regarding the choice of suitable wire electrode materials and the influence of the properties of these materials on the machinability in WEDM. Lee et al. [27] carried experiments on WEDM assisted by ultrasonic vibration of the wire has a better machining result than that of wire cut alone. In order to study its machining mechanism, the methods of experiment as well as simulation have been used to verify some hypotheses and interpretation. By means of experiments employing single pulse discharge it has been established that the high frequency vibration of the wire electrode is able to bring about multiple channel discharges so that better surface quality and a high cutting rate can be obtained simultaneously. The simulation of the dynamic characteristics of the wire electrode under the action of continuous discharge forces shows that ultrasonic vibration facilitates the shift of the discharge points and improves their distribution. A set of statistical experiments has been designed to analyze the utilization of the pulse. It is revealed that with ultrasonic vibration there is a greater utilization of energy, which is a critical factor in securing an increase in the cutting rate.

In 1998 McGeough et al. [28] cumulate intelligent knowledge-based system for evaluating wire-electro-erosion dissolution (WEED) in a concurrent engineering (CE) environment and based on object-oriented techniques, is introduced. The design description is obtained through a feature-based approach. Nine different classes of design features are interactively acquired. The attributes of steel as a work-piece material, copper wire as a tool material, a single electrolyte solution, one type of WEED machine, and machining conditions such as current pulse on- and off-time, and nozzle distance, are stored in a database. For each design feature, information needed in manufacturing, such as the machining cycle time and cost, material removal rate, width of cut, maximum and working feed-rate, cutting area, and operation efficiency are estimated. Y.F. Luo [29] presented the application of wire EDM, wire rupture is very troublesome and impedes further increase of cutting speed. Instead of the spark characteristics or the temperature distribution, the rupture mechanism and the mechanical strength of the wire are the focus of investigation. Wire rupture is a mechanical failure in essence, although the process heat has significant influence on the occurrence of the failure. In general, wire tension and spark pressure are the two major causes for wire rupture. The two loads need to be increased with the increase of cutting speed and the reduction of bow tolerance. Only the careful design of the wire material and structure can assure the required wire strength in application especially when high cutting speed is attempted with a tight bow tolerance.

Puri and Bhattacharyya [30] experimented on the wire lag phenomenon in WEDM and the trend of variation of the geometrical inaccuracy caused due to wire lag with various machine control parameters has been established. In an extremely complicated machining process like Wire-cut EDM, which is governed by as many as ten control factors, it is very difficult to select the best parametric combination for a particular situation arising out of customer requirements. In their research study, all the machine control parameters are considered simultaneously for the machining operation which comprised a rough cut followed by a trim cut. The objective of their study has been to carry out an experimental investigation based on the Taguchi method involving thirteen control factors with three levels for an orthogonal array L_{27} (3^{13}). The main influencing factors are determined for given machining criteria, such as: average cutting speed, surface finish characteristic and geometrical inaccuracy caused due to wire lag. Also, the optimum parametric settings for different machining situations have been found out.

In 2003 Han, Wachi and Kunida [31] describes the improvement of machining characteristics of micro electrical discharge machining (micro-EDM) using a newly developed transistor type isopulse generator and servo feed control. The *RC* generator is mainly applied in conventional micro-EDM even though the transistor type isopulse generator is generally more effective for obtaining higher removal rate. Wang and Ravani [32] develop a computational method for numerical control (NC) of traveling WEDM operation from geometric representation of a desired cut profile in terms of its contours. Normalized arc length parameterization of the contour curves is used to represent the cut profile and a subdivision algorithm is developed together with kinematics analysis to generate the required motions of the machine tool axes. In generating the tool motions for cutting sections with high curvatures such as corners with small radii, a geometric path lifting method is presented that increases the machining gap and prevents gauging or wire breakage. In 2004 Obara et al. [33] described corrosion of a work-piece of cemented carbide submerged in a dielectric of water for a lengthy time during WEDM. When the cemented carbide is submerged in water for a long time, the surface of the cemented carbide becomes brittle, because the cobalt which is the binder of cemented carbide is dissolved in the water. This occurs even if an AC power generator is used during the wire EDM. Altpeter and Perez [34] established the relationship between the dynamics of the wire electrode and the state of the art in WEDM control is established through wire modeling, listing the control issues related to WEDM and providing a catalogue of corresponding solutions. The results are to be used for identifying promising R&D directions in terms of customer convenience, and set up cost reduction by an improved process mastering. Yan and Huang [35] improved the machining accuracy by a closed-loop wire tension control system for a wire-EDM. PI controller and one-step-ahead adaptive controller are employed to investigate the dynamic performance of the closed-loop wire tension control system. In order to reduce the vibration of wire-tension during wire feeding, dynamic absorbers are added to the idle rollers of wire transportation mechanism. Experimental results indicate that the geometrical contour error of corner cutting is reduced with approximately 50% and the vertical straightness of a work-piece can be improved significantly.

Newman et al. [36] found that WEDM is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp.. A significant amount of research has explored the different methodologies of achieving the ultimate WEDM goals of optimizing the numerous process parameters analytically with the total elimination of the wire breakages thereby also improving the overall machining reliability. It reports on the WEDM research involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity. In 2005 Yan et al. [37] investigated the feasibility of fabricating micro-holes in the high nickel alloy using micro-electro-discharge machining (micro-EDM). The high nickel alloy is a material with high magnetic permeability. It can be used to shield MEMS prevent interference of the magnetic field. Micro-systems can be assembled and micro-wires can be connected through micro-holes that are drilled in the work-piece. Scott F. Miller et al. [38] Studied the WEDM of cross-section with minimum thickness and compliant mechanisms. Effects of EDM process parameters, particularly the spark cycle time and spark on-time on thin cross-section cutting of Nd–Fe–B magnetic material, carbon bipolar plate, and titanium are investigated. An envelope of feasible wire EDM process parameters is generated for the commercially pure titanium. The application of such envelope to select suitable EDM process parameters for micro feature generation is demonstrated. Scanning electron microscopy (SEM) analysis of EDM surface, subsurface, and debris are presented.

Huang et al. [39] displayed the surface alloying behaviour of tempered martensitic stainless steel multi-cut with WEDM. Before machined with WEDM, the steel specimens were quenched at 1050□C and then tempered at 200□C, 400□C, and 600□C, respectively. The microstructure and surface morphology of the multi-cut surfaces were examined with scanning and transmission electron microscopes integrated with an energy-dispersive X-ray spectrometer for chemical composition analysis. In 2006 Chern et al. [40] developed the micro-tools that are fabricated by micro-EDM using the WEDG method in the micro-EDM/milling machine. Micro tungsten-carbide tool with a minimum of 31-μm in diameter had been fabricated. The simple-shaped micro-tool fabricated is able to perform the micro-machining operation which is a combination of micro-milling and grinding processes. Micro-slot and micro thin-walled structure had been produced on Al 6061-T6 materials successfully. Burr formation in micro-machining is investigated experimentally and classified into four types: primary burr, needle-like burr, feathery burr and minor burr. Norliana Mohd Abbas et al. [41] studied that EDM process is based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporizing. The electrode and the work piece must have electrical conductivity in order to generate the spark.

In 2007 I. Cabanes [42] found that the main challenges in WEDM is avoiding wire breakage and unstable situations as both phenomena reduce process performance and can cause low quality components. This work proposes a methodology that guarantees an early detection of instability that can be used to avoid the detrimental effects associated to both unstable machining and wire breakage. The proposed methodology establishes the procedures to follow in order to understand the causes of wire breakage and instability. Hideo Takino et al. [43] investigated the effect of cutting by WEDM on the shape accuracy of polished single-crystal silicon. Single-crystal silicon plates are polished, and then contoured in de-ionized water or in oil by WEDM. The shape accuracy of the polished surfaces is measured with an interferometer. As a result, the polished surfaces are deformed into convex shapes by WEDM cutting. The polished surfaces tend to become flat as the roughness of the cut sections decreases, and the flatness is independent of the type of cutting liquid. Cutting in-oil is advantageous for maintaining the smoothness of polished surfaces.

IV.CONCLUSION

After the thorough study of literature it has been observed that still there exist space for research in this field. The challenges for future have been described below:

- There has been a little research has been observed on recast layer thickness and its removal.
- A number of techniques developed for the processing and analysis of data which are particle swarm optimization, genetic algorithm, fuzzy logic and artificial neural network.
- Some novel material like metal matrix composite can also be another thrust area for research.
- Hybridization of the process is another challenging task for future investigations.

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