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Research trends in Wire electrical discharge machining (WEDM): A Review

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Abstract- **Wire electrical discharge machining (WEDM) is a non-conventional machining process for cutting hard materials using water as a dielectric medium. WEDM is used in various disciplines like as auto sector, aero-space sector, medical sector, tool and die manufacturing companies. Present research shows its application into development and optimization of process parameters needed to implement this cutting edge technology into industrial applications.**

Keywords: WEDM, MRR, ANN, SEM, APM, Fuzzy controller, modeling.

1. INTRODUCTION

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of conductive materials like copper, brass or tungsten of diameter 0.05-0.30 mm. The wire is kept in tension using mechanical guides. 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. The WEDM machine tool comprises of a main worktable (X-Y) on which the work piece is clamped; an auxiliary table (U-V) and wire drive mechanism [6]. The main table moves along X and Y-axis and it is driven by the D.C servo motors. The X-Y controller of the machine displaces the worktable carrying the work piece transversely along a predetermined path programmed in the controller The travelling wire is continuously fed from wire feed spool and collected on take up spool which moves though the work piece and is supported under tension between a pair of wire guides located at the opposite sides of the work piece. The lower wire guide is stationary where as the upper wire guide can be displaced transversely along U and V-axis with respect to lower wire guide. The upper wire guide can also be positioned vertically along Z-axis by moving the quill. A schematic Diagram of the Basic Principle of WEDM process is shown in Fig 1.1.The process parameters play a vital role in the efficient cutting of material on the WEDM. To optimize the process parameters the design of experiment is employed to get maximum insight with minimum number of experiments [23-25].

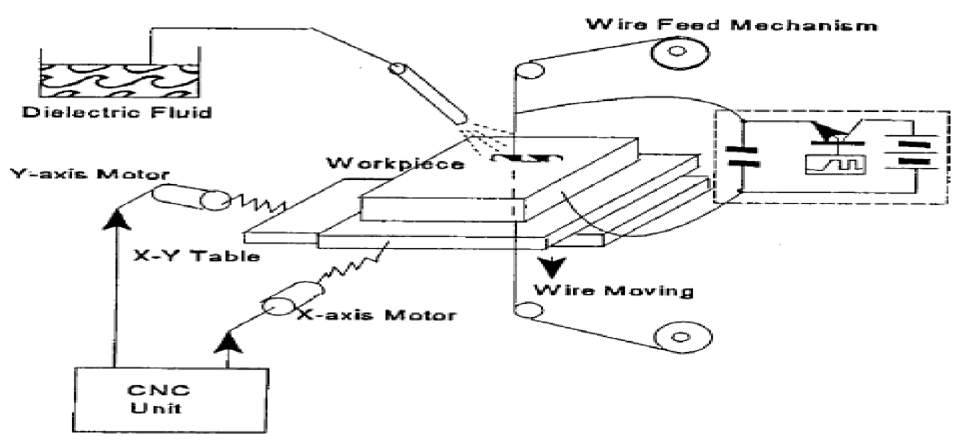

Figure 1.1: Schematic Diagram of the Basic Principle of WEDM Process

2. WIRE ELECTRICAL DISCHARGE MACHINING PARAMETERS

2.1 Pulse on Time: -

The pulse on time is referred as Ton and it shows the duration of time in seconds, in this current is flowing in each cycle time. An amount of voltage is applied across the wires during that particular period. Ton range for setting time represented for the machine tool is applied in steps of 1 unit.

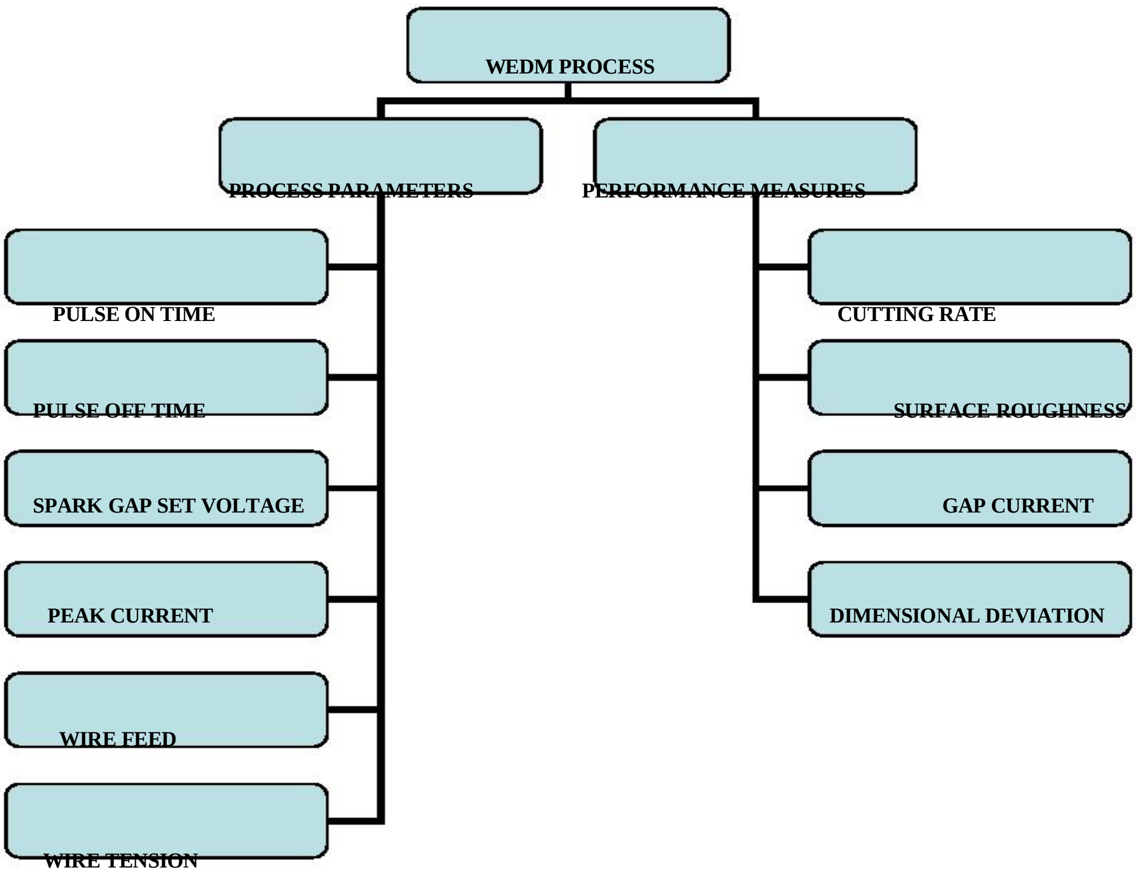

Figure 1.2: Process Parameters and Performance Measures of WEDM

2.2 Pulse off Time:-

The pulse off time is referred as Toff and it represents the duration of time in micro seconds, µs, between the two simultaneous sparks. The voltage is absent during this part of the cycle. The Toff setting time range available on the machine tool is applied in steps of 1 unit. To avoid such problem off time must be inserted as shown in figure 1.3.

2.3 Peak Current:-

The peak current is represented by IP and it is the maximum value of the current passing through the electrodes for the given pulse. The setting of peak current sort available on WEDM machine which is applied in steps of 10 ampere. Increase in the IP value will increase the pulse discharge energy.

2.4 Spark Gap Set Voltage:-

This is a reference voltage for the actual gap between the work piece and the wire used for cutting.

2.5 Wire Feed:-

Wire feed is the rate at which the wire-electrode travels along the wire guide path .It is always required to adjust the feed of the wire to a maximum speed. level. Proper wire feed provides better results like as less wire breakage, better machining condition and slightly more cutting

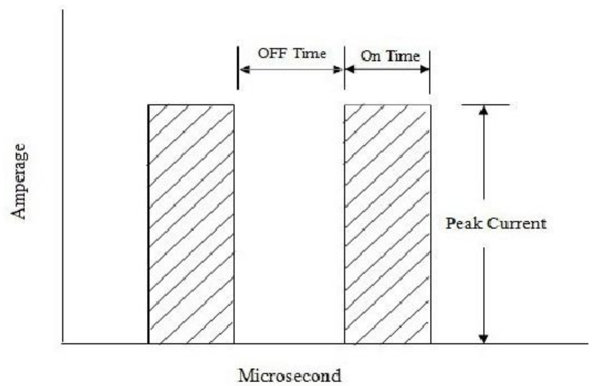

Figure 1.3: Pulse on Time and Pulse off Time

2.6 Wire Tension:-

Wire tension determines how much the wire is to be stretched between upper and lower wire guides. This is a gram-equivalent load with which the continuously fed wire is kept under tension so that it remains straight between the wire guides.

2.7 Pulse Peak Voltage:-

Pulse peak voltage setting is for selection of open gap voltage. The pulse peak voltage setting range available on the machine is either odd or even .Normally its value selected on even.

2.8 Flushing Pressure:-

Flushing Pressure is for selection of flushing input pressure of the dielectric. High input pressure of water dielectric is necessary for cutting with higher values of pulse power and also while cutting the work piece of higher thickness. Lower value of input pressure is used for thin work piece and in trim cuts.

2.9 Servo Feed

Feed setting device decides the speed of servo; the servo speed, at the set value of servo feed, can vary in proportion with the gap voltage or can be held constant while machining.

3. LITERATUREREVIEW

N. Kinoshita et al. [9] worked on wire-EDM for checking the performance of wire used as an electrode. The aim of work was to study various conditions on which breakage of electrode will takes palace. Avoidance of electrode from breakage was considered as a main part of the problem. Once the wire breakage occurs, it inflicts a severe harm in wire-EDM, takes place in the form of machining process. In that process provided the supply of work piece at lower speed for best results. Thus it was very important to know the feedback report of wire breakage which was detected by a feedback system. After studied these factors, that research told about why breakage of wire takes palace, and developed a model for analyzing the frequency of pulse.

Y.S.Liao et al. [18] observed that the appropriate choice of machining parameters for WEDM process depends upon operator's personal experience and technical knowledge. Data regarding the machining-parameters could not meet the machinist requirements. Because for required surface roughness they do not offered the best environment for machining. An approach was used for parameters setting which based on Taguchi quality design method and the examination of variation. Important factors affecting the performance of a machine such as MRR, SR and sparking frequency were determined. Using regression analysis and mathematical models a series of machining parameters were determined. By using mathematical models an objective function was formed with the help of some definite conditions. The optimization problem was solved for obtaining best machining parameters using realistic direction technique.

Minyang Yang and Eungki Lee [5] had done time consuming and unproductive experiment on wire-EDM with the help of NC codes. In this work, an algorithm prepared in Data structure was applied on the problem to check the feasibility of NC programming. R-map model was used for representing the distinct surface with the help of r-values considers at the network point. After that compared the geometry of final object with the help of standard data received from CAD. At last NC programs for WEDM were verified in c++ programming language. The developed system was in the form of wire electrode having output in colored form and depth of colored surface was depends upon the extent of machining error.

M. T. Yant and S. Liaot [7] worked with the help of fuzzy control technique and monitored the condition of wire rupture in wire electrical discharge machining. Breakage of wire was a serious problem WEDM was developed a system of voltage waveform which used in monitoring the sparking frequency in control system. . A fuzzy controller was proposed to control the frequency of spark by adjusting the pulse off-time for wire rupture minimization and also for higher MRR. The developed strategy was tested according to various conditions such as work piece cut with continuous sharp angles, work piece height change during the time of operation and operated with high feed-rate.

S.Banerjee et al. [11] studied heat conduction phenomena in 3D when worked on WEDM for calculated the rate of erosion in wire electrode. That research covered transient temperature distribution and crater formation of the electrode in 3D for the duration of a single discharge and measured with the help of finite-difference model. With the help of boundary condition which is related to heat flux find out the value of load acting on the wire. Value of heat-flux is measured with the help of input power and diameter of the channel which was used for discharge. At last they compared final results with experimental data and conclude that system melting point was depends on crater shape.

Y. S. Liao et al. [19] studied wire breakage process of WEDM taken wire rupture as a major problem. Computer-aided pulse discrimination arrangement was generated which depends on voltage waveform .With the help of this arrangement measured and analyzed the data of sparking frequency. Wire ruptures were traced in the form of sudden increment in the value of arc spark and rise in aggregate spark frequency. Governing mechanisms for wire rupture was found with the help SEM and other important techniques. At last a relation was identified between various machining parameter and wire breakage during the operation on WEDM.

T.A.Spedding and Z. Q. Wang [13] studied surface qualities and effective parameter setting in wire electric discharging machining. Wire electrical discharge machining (WEDM) technology has been widely used in conductive material. For machining the conductive materials WEDM process had been in practice. That process was a combination of electro dynamic and magnetic as well as thermal dynamic. Surface condition and production of machine was depends on several factors. Research presented an attempt to solve the problem with the help of artificial neural networks (ANN) technique and shows the surface of machine with the help of time series techniques.

T.A.Spedding and Z. Wang [14] worked on WEDM and understood the modeling process used during time of operation. WEDM process was used in the field of manufacturing, space and all areas of machining used for conductive material. This paper considered modeling process using RSM and ANN techniques. A response surface model developed with the help of a central composite rotatable design, and 4-16-3 size back-propagation neural techniques. These four parameters like as time between two pulses, pulse-width, wire tension and injection set-point was considered as an input parameter while output parameter like surface roughness, cutting speed and waviness were taken for the process. Comparison and Verification of trails had been carried out to check the validity of the models. It was concluded that these models provide exact results for the process.

W. M. Wang and W. S. Zhao [16] studied adaptive control system used in wire electrical discharge machining having a model of multiple inputs for checking the height of work piece. In WEDM changed the value of power density observed small reduction in value of output and wire rupture. Research presented adaptive control system used in WEDM that optimizes the frequency of spark. In this work measured the height of work piece with the help of various input models. These models told the relations between feedback voltage due to gap, frequency of spark and feed rate of machine table. Wide range of experiments performed for check the feasibility of new model.

N.Mohri et al. [10] worked on Wire Electrical Discharge Machining for Identification of the system. In WEDM it was very important to brought under control the vibration of wire electrode for the enhancing the accuracy during the time of machining. Present research investigates wire vibration mechanism in dynamic condition and generated mathematical model. Result from trails was compared with generated model. The process of analysis and measurement was occurred in WEDM during the machining of a thin plate through desired response of a single discharge. Force acting on electrode depends on the direction of electrode motion in the vibration mode. Equation based on 3^{rd} order was derived for considering material removal and vibration features. Finally results showed the simulation of WEDM with an equation model.

M. T. Yan et al. [8] investigated these three parameters wire breakage, metal removal rate (MRR), and surface roughness. Fuzzy based on operator technical knowledge and experience was developed by changing the value of servo-feed and pulse off time. In that they worked on adaptive control system in WEDM used Fuzzy control techniques with the help of adaptive Final outcomes showed that developed control system was satisfactory.

W.J.Hsue et al. [17] studied geometry analysis of WEDM in case of corner cutting. The idea of discharge-angle was developed by the analytic geometry method. Further a model was designed for finding the value of MRR in case of geometrical cutting. After finding the value of MRR its value compared with sparking frequency. Minimum value of MRR and discharge angle depends upon corner angle. Finally outcomes showed that increased in gap-voltage and decrement in sparking frequency in case of corner cutting changed.

T. Huang et al. [15] worked on finish-cutting operation and machining-parameters in wire electrical discharge machining. Wire electrical discharge machining (WEDM) mainly used in precision manufacturing and used to obtained a work piece of higher accuracy. Input parameters like pulse-on time, pulse-off time, flushing pressure and table feed-rate was considered for the response parameter like surface roughness, gap width, depth of white layer. They concluded that most affecting parameters were pulse-on time and distance between wire borders. Final outcomes showed that the proposed approach could get better performance than that of previous one. Better surface quality and correct dimension obtained in less machining time.

Y. F. Luo [20] performed test on wire used in WEDM and find out mechanical strength and rate of failure due to rupture In WEDM, wire rupture was troublesome and increase the cutting speed. Due to excess heating wire rupture was occurred. Before strength analysis of wire, suitable ratio of wire tension was taken for tolerance related to wire bow. For that a stress model was developed to elaborate stress distribution and got the solution with the help of Airy's function. Analysis was carried out for yield strength to check the effect of load and other factors on yielding of wire. For finding the value of yield strength and toughness check the relation among various parameters like as load, material properties and geometrical properties. At last they conclude that spark pressure and wire tension played an important role in wire rupture.

Liao and J. Woo [21] designed a fuzzy controller in WEDM process act as an adaptive control system. In that research a fuzzy controller was designed for controlling the complete WEDM process. Power consumption and circuit ratio was taken as controlling parameters for control the whole process. By using pulse trains data and experience, a model was designed with the help of fuzzy rules for controlling WEDM process. A monitoring system was developed based on DSP and fuzzy control method was implemented on a PC-486. They developed a control system having a reference level of power and feed and set according to the machine power. At last they designed a model of control strategy and compared with a conventional control system.

A.M. Ozano [3] investigated the effects of cutting parameters on surface condition. Research aim was to select cutting and offset parameter in a suitable combination for WEDM to find out the value of desired surface roughness for machined pieces. Various experiments were performed on steel pieces of various thicknesses like as 80, 60 and 30 mm. The test specimens was cut using different combinations of cutting and offset parameter at CAD centre of technical University of Middle East. At last they obtained standard charts and tables for selecting desired surface roughness of different work piece.

Y. S. Liao et al. [22] measured work piece height on line by neural network approach. In that research for measuring the work piece height at different machining conditions used feed forward neural technique. Several trails were carried out to check the benefits of this approach. A rule-based strategy was introduced maintaining stable and optimal machining condition. According to that strategy, value of power and servo voltage adjusted for checking the profile of work piece. At last results showed that efficient and stable machining achieved by rule-based strategy.

C. A. Huang et al. [4] tested to check the surface qualities of multi-cut high-speed steel (ASP 23) in powder form by WEDM. Powder-metallurgy (P/M) process was used for manufacturing high speed steel. Its wider range of application was in mold of I/C packing subjected to machining by multi-cut WEDM used brass wire. Before machining, steel was quenched and tempered at 1180 ◦C and 560 ◦C respectively. Cut surface was examined and analyzed by scanning electron microscope (SEM) and anodic polarization measurement (APM) techniques respectively. At last they conclude that a recast layer was obtained in between alloys of steel and electrode wire materials by transforming the initial structure in martenstic form.

S. Kuriakose et al. [12] worked on WEDM using data mining approach. Due to non-linear behavior WEDM was considered highly complex process .Model that process by data mining used several input parameters based on machine learning. The model was trained by data collected through various trails. Additional data was also used for testing that model. At last they conclude that the model built by using data mining given better results with preferred accuracy.

A.B. Puri and B. Bhattacharyya [1] studied wire-tool vibration during the process of wire-cut EDM.WEDM used in various industries like metal cutting industries, die making industries and press tool industries.Some modification was required for achieving the better qualities of product with high precision. That research showed that vibration behavior of electrode and solved wire tool vibration equation by using analytical approach considering multiple spark discharge. At last they conclude that output was depends upon pulse discharge frequencies under maximum value of wire tool vibration.

A.B. Puri and B. Bhattacharyya [2] studied the concept of wire lag phenomenon in WEDM process. In that research they studied wire lag phenomenon and developed various machine control parameters for controlling the geometrical inaccuracy occurred due to wire lag. Ten control factors was taken in Wire-cut EDM and use of these factors in combination is very much difficult according to the need of the customer.. In that research all control parameters for a machine were taken simultaneously for the machining of a work piece which used a rough cut derived from a trim cut. They performed experiments on WEDM considering thirteen control factors using Taguchi method as a optimization technique. At last they observed best possible parametric settings for different machining conditions

After a complete study of the existing literature, a number of gaps have been observed in machining of Wire Electrical discharge machining. Most of the scholars have investigated influence of a limited number of process parameters on the performance measures of WEDM parts. Literature review reveals that the researchers have carried out most of the work on WEDM inventions, periodic checking and control but a very small amount of work has been reported on optimization of process variables. Multi-response optimization of WEDM process is another thrust area which has been given less attention in past studies. Value of MRR is changed by changing pulse on time. By decreasing pulse duration and discharge current obtained superior surface flatness. This indicates that a short pulse duration combined with a high peak value can generate better surface roughness, which cannot be obtained with the help of lengthy pulses. Machining occurs in reverse polarity with the suitable pulse energy can improve the machined surface roughness somewhat better compared with normal polarity in finish surface. It was taken in consideration, during trails that the pulse on time and pulse off time influence the wire breakage more than any other parameters considered in this machining process. By positive change in the value of pulse on time & wire tension increase wire wear ratio. The main objective of the WEDM process is to obtain the optimal parameters without making compromise with its performance measures, by use of different multi-optimization methods.

The recent advancement in the materials has become a challenge for WEDM process to be used in the upcoming time period. It is very essential to make nonstop development in the current WEDM process to increase their productivity and efficiency.

A number of techniques developed for the processing and analysis of data like as artificial neural network, fuzzy logic and genetic algorithm. 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.

4. 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 observed on wire lag phenomenon in WEDM.
- A number of techniques developed for the processing and analysis of data which are fuzzy logic and artificial neural network are still need to be explored for developing rugged models for WEDM of hard to machine materials.
- Some novel material like metal matrix composite can also be another thrust area for research, as development of newer materials through various techniques is witnessed on a very fast pace.
- Hybridization of the process is another challenging task for future investigations, ultrasonic vibration and combining with other non-conventional processes still is in the nascent stage.

In nutshell it can be concluded that the wire electric discharge machining is a very popular non conventional machining process which still needs to be explored by researchers for efficient cutting of hard to machine materials.

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