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"Research Work for Optimization and Effect of WEDM Cutting Process Parameters on Performance Measures- a Literature Review"

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***Abstract:** Use of traditional machining methods to machine intentionally developed new hard, tough and reinforcement materials is no longer efficient due to greater tool wear, which causes serious surface damage. Thesekinds of materials can be machined with the help of non-traditional machining methods. WEDM is one of the non-traditional methods which provide greater degree of surface finish with high MRR while cutting electrical conductive materials. WEDM performance estimation is based on MRR (Material Removal Rate), WWR (Wire Wear Rate), Kerf width and SR (Surface Roughness). Lots of work has been done by various researchers on WEDM process parameter optimization for various materials.This paper presents a literature review of work done on optimization of various cutting process parameters like: Pulse on time (Ton), Pulse off time (Toff), Wire feed rate, Peak current, Servo voltage, Spark gap set voltage etc.) and the effect of these cutting parameters on performance measures like (MRR, WWR, kerf width and SR etc.) on WEDM.*
***Keywords-** MRR, SR, WWR, Kerf width, Process parameters, Performance measures, WEDM.*

I. INTRODUCTION

Wire electrical discharge machining (WEDM), is a spark erosion process used to produce complex two and three-dimensional parts of electrically conductive work pieces by using wire as an electrode. WEDM is a non-traditional machining process that uses electricity to cut any conductive material precisely and accurately. During the WEDM process, the wire carries negative side of an electrical charge and the work piece carries positive side of the charge. When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, which melts and vaporizes microscopic particles of material. The spark also removes a small part of the wire, so after one cut, the machine removes the used wire and automatically advances new wire with the help of wire feeding mechanism. This process takes place quickly, thousands of sparks per secondgenerated but there is a small gap between wire and work piece. Wire EDM machines use a dielectric solution of deionized water to continuously cool and flush the machining area while EDM is taking place. In many cases the entire part is submerged in the dielectric fluid, while high-pressure upper and lower flushing nozzles clear out microscopic debris from the surrounding area of the wire during the cutting process. The fluid also acts as a non-conductive barrier, preventing the formation of electrically conductive channels in the machining area. When the wire gets close to the part, the intensity of the electric field overcomes the barrier and dielectric breakdown occurs, allowing current to flow between the wire and the work piece, resulting in an electrical spark. This electric spark initiates the material removal process. Figure 1 shows the WEDM process [1].

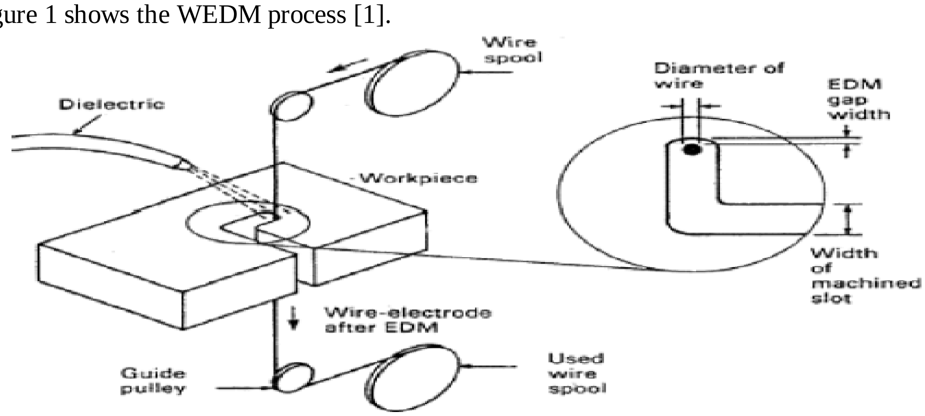

Figure 1 – WEDM Process

The high degree dimensional accuracy of work piece and the surface finish makes WEDM particularly valuable for applications involving manufacturing of stamping dies, extrusion dies and prototyping parts. Without WEDM the fabrication of precision work pieces requires many hours of manual grinding and polishing. Presently WEDM is also used in the field of medicine, electronics, automotive, aerospace, defense industries etc.

Discharge current, discharge capacitance, pulse duration, pulse frequency, wire speed, wire tension, average working voltage and dielectric flushing conditions are the machining parameters which affect the performance measures like: MRR (Material Removal Rate), WWR (Wire Wear Ratio), kerf width and SR (Surface Roughness).Among the other performance measures, the kerf width which determines the dimensional accuracy of the finished part is of utmost importance. The gap between wire and work piece usually ranges from 0.025 to 0.075 mm, it is maintained by a computer controlled positioning system. In WEDM operations, material removal rate (MRR) determines the economics of machining and rate of production. In setting the machining parameters, the main goal is the maximum MRR with the accurate kerf width and minimum SR[1,2].

II. LITERATURE REVIEW

H.K. Sharma et. al. suggested an investigation on effect and optimization of input machining parameters for output parameters cutting speed, kerf width, and surface roughness in WEDM using H21 die tool steel as work piece. Tungsten wire is used as tool electrode in this work. Taguchi's L18 Orthogonal Array was used to perform experiments. Discharge current, Pulse ON time, Pulse OFF time, Wire Feed and Wire Tension was used as input process parameters. Percentage contribution of selected input parameters was finding by using ANOVA. This research suggested that average cutting speed was mostly affected by pulse ON time, pulse OFF time and wire feed during ruff cut and surface roughness has no significant affect by any selected factor. Kerf width was mostly affected by discharge current, pulse ON time, pulse OFF time and wire feed during ruff cut [3]. S. Kumar et. al. suggested the effects of input process parameters on MRR of WEDM using Stainless steel (SS 304) as work piece. A brass wire and diffused wire of 0.25mm diameter has been used as tool electrodes. Pulse ON time, Pulse OFF time and Voltage were selected as input process parameters. The DOE was based on Taguchi's design approach L9 Orthogonal Array and results obtained by Taguchi's design approach were analyzed by ANOVA. This study concluded that diffused wire gives more MRR as compared to the brass wire. It was also concluded that pulse ON time and servo voltage has the highest influence on MRR. As pulse ON time increases the MRR increases. On the other hand, when pulse OFF time and servo voltage increases the MRR decreases [4]. V. Kumar et. al. presented a practical work on rough cut and trim cut using distilled water as a dielectric fluid and Al-Si metal powders in water as another dielectric fluid for WEDM using Nimonic-90 as working metal. Discharge energy (DE) was taken as input parameter with varying concentrations of Al-Si metal powders in dielectric fluid (1g/L, 2g/L and 3g/L was studied separately) and MRR, surface roughness, recast layer and micro hardness was taken as output parameters. The effect of discharge energy (DE) in rough cut was checked for MRR and surface roughness and compared with trim cut without any metal powder added in dielectric fluid. From the results, it was concluded that by using trim cut, a fine and uniform surface texture was obtained irrespective of the high discharge energy (DE) in rough cut. Result also shows that MRR reduced when Al-Si powders used as additives in trim cut, on the other hand a remarkable modification was obtained in surface texture in trim cut using metal powder additives. Surface roughness improved when 1g/L concentration was used. Recast layer was become smooth and denser by using metal powders, thus, micro hardness increases [5]. A. Goswamiet. al. stated the analysis of trim cut WEDM using Nimonic-80A as work piece through input machining parameters peak current, peak voltage, pulse ON/OFF time, wire speed, wire tension, wire offset, spark gap and flushing pressure to prescribe output machining parameters such as material removal rate(MRR), surface roughness, wire wear ratio(WWR), and microstructure analysis. Electronica Sprintcut(Electra- Elplus 40A DLX) CNC wire electrical discharge machine was used to perform experiments employed with brass wire electrode (Bravo plus) of diameter 0.25 mm (Soft) and De-ionized water was used as the dielectric fluid. Taguchi's DOE methodology was used for executing the experiments. ANOVA was employed for the analysis and evaluation of significance of various affecting factors. The lucent results elaborate the potential of trim cut for high surface finish compared to rough cut machining [6].B. Choudhuriet. al. provided optimization in WEDM process on H21 tool steel. H21 exhibits superior red hardness, high mechanical strength, and low machinability and thus used as hot work tool steel. ELEKTRA SPRINTCUT CNC wire electrical discharge machine was used with Soft brass wire (0.25 mm diameter) as tool electrode. Cutting speed decides the productivity of WEDM and kerf width provides tolerance of finished product. Two methodologies viz. response surface method (RSM) and artificial neural network (ANN) were compared regarding their modeling, sensitivity analysis and optimization abilities which concluded that the predictability of ANN model is better than RSM which emphasize the advantage of ANN in mapping the nonlinear behavior of the system. However, the ANN fitness function is integrated with particle swarm optimization (PSO) algorithm to optimize the output process parameters of the WEDM process [7]. B.

Sivaramanet. al. evaluated the effect of various control parameters on WEDM using Titanium as work piece. The input process parameters included Dielectric pressure, Pulse ON/OFF time, Wire tension, Wire feed rate, Gap voltage, and Average gap current which effect the output response parameters such as Surface roughness, Electrode wear, Material removal rate were studied through orthogonal arrays and L9 techniques of Taguchi method, and concluded in favour of Taguchi method regarding parametric optimization of WEDM on using multiple performance characteristics such as MRR and surface roughness [8]. R.M. Chaudhariet. al. in his work input process parameters affecting quality characteristics (output parameters) in WEDM process was studied. In this study, it was concluded that Surface roughness and MRR plays vital role in machining processes. Input parameters like voltage, pulse ON/OFF time, dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters for optimization of WEDM. Signal to noise ratio measuring system was used to obtain MRR and surface roughness. Optimal value for surface roughness and MRR was determined by using Multi objective optimization techniques GRA and ANOVA and by using Taguchi optimization technique, optimized value was determined for MRR and surface roughness separately which can be used to obtain minimum surface roughness and maximum MRR [9]. S. Sivanagaet. al. provided the best process parameters of WEDM in machining 18-4-1 grade speed steel (HSS) with different thickness varies from 5mm to 80mm. Experiments were executed under various conditions by varying power inputs and with stable machining and high cutting speeds. And all output performances are evaluated with different thickness of work piece material and therefore results in development of correlations with using software, these correlations and parameter evaluations were studied to choose best process parameters [10]. A. Joshi et. al. examined the control process parameters of WEDM to elaborate process limitations for tool and die steel. This research work has been done to examine the cutting and metal removal rate of tool steel EN 31. ELECTRONICA DL-25P unit 4-axis CNC WEDM with Brass wire of diameter 0.18 mm was used for experiment work. Pulse ON time, pulse OFF time, bed speed and current was input process parameters. Obtained results were examined using S/N ratios, response graph and response table in Minitab software. In this practical work results were analyzed and regression equation was developed to calculate the MRR. It was concluded that with increase in pulse ON time and bed speed, MRR increases, and low pulse OFF time results in low MRR [11]. P. Abineshet. al. studied the effect of working process parameters in WEDM using Titanium Alloys as work piece. Experiments were carried out on ELEKTRA SPRINTCUT 734 WEDM machine using Brass and Brass Coated Nickel wire of diameter 0.15-0.20 mm. Relation between the various input process parameters like Pulse ON time (Ton), Pulse OFF time (Toff), Pulse Peak Current (IP), Wire material and Work piece material and process variables was investigated to optimize output process parameters like MRR, Surface Roughness and Electrode Wear Rate. Taguchi's L16 orthogonal array was selected to optimize values of chosen process parameters. In this work, it was concluded that with high values of pulse ON/OFF time and low value of current MRR increases. When there was an increment in pulse ON time Surface Roughness decreased and with an increment in pulse OFF time and peak current surface roughness increased. Electrode wear rate reduced when pulse OFF time and peak current increased [12].D.V. Kashidet. al. in this research investigation on effect of input process parameters on MRR in WEDM machining process of Steel Grade EN 9 was done. Experimental work was performed on SPRINTCUT ELPULS 40 A DLX CNC WEDM using a negatively charged brass wire of diameter of 0.25 mm. Three input process parameters were chosen, pulse ON time (Ton), pulse OFF time (Toff) and wire feed. Taguchi's L9 orthogonal array was used to perform experiments and signal to noise ratio was estimated for MRR. Analysis work was performed using ANOVA and response graphs. At last it was found that MRR mostly influenced by Ton and Toff. Maximum MRR was obtained by using high value of Ton and low values of Toff and wire feed. Wire feed have minimum effect on MRR [13].N.Z. Khan et. al. studied the effect of WEDM process parameters on surface roughness average and micro hardness of HSLA (High Strength Low Alloy Steel) ASTM A572-grade 50. Taguchi's orthogonal array and grey relational analysis (GRA) method was subsequently applied to determine an optimal WEDM parameter setting through nine experiments. Experiments were executed on a Steer Corporation DK7712 NC WEDM machine. The pulse OFF time was found to be the most important factor for both the surface roughness and the micro-hardness. This work gave results that Increased pulse ON time leads to the increase in both the surface roughness and the micro-hardness. Increase in the pulse current results in increased surface roughness. The fruitful order for the controllable input factors to the surface roughness average was in sequence, pulse OFF time, pulse ON time, and the current. However, for micro-hardness the sequence was the pulse OFF time, the current and the pulse ON time [14].P.S. Raoet.al. investigated effects of input parameters WEDM on MRR by employing Aluminum BIS-24345 alloy for work piece material. Taguchi design L_{18} orthogonal array was used for study of Different levels of input parameters. Pulse on time, Pulse off time, Peak current, flushing pressure of dielectric, wire feed rate, wire tension, spark voltage & servo feed were selected as input parameters. First orthogonal array was used for preparation of table then analysis was done through ANOVA and finally MRR is calculated with S/N ratio. Through experiments, it was determined that Peak current was most substantial parameter, while Pulse on time, Pulse off time, Spark voltage and Flushing pressure of dielectric were other prominent parameters. While wire feed and wire tension were less important parameters [15].L. Li. Et. al. checked on the evolution of surface integrity and machining efficiency of WEDM when machining Nickel-based Alloy (IN718). One rough cut (RC) mode and three trim cut (TC) modes were used for this study. Studied machining parameters were material removal efficiency, surface roughness, surface topography, surface alloying and micro hardness. Results explained that Surface roughness in RC mode was different than TC modes. In TC modes micro cracks absent, high toughness of IN 718 would have been the reason for this absence. Micro-cracks exists in white layer of 6-8 µm thickness in RC mode and thin white layers of 0-2 µm free from micro-cracks was observed in TC2 mode. In TC3 mode white layer was invisible [16].A. Goswamiet. al. in his research surface integrity, material removal rate (MRR) and wire wear ratio was investigated for WEDM process using Nimonic 80A as work piece material. ELECTRONICA SPRINTCUT (Electra- Elplus 40A DLX) CNC WEDM was used to perform experiments using soft brass wire of diameter 0.25 mm as tool electrode. Experiments were designed based on Taguchi's design of experiments (DOE). Input process parameters taken was peak current, pulse ON time, pulse OFF time, wire speed, wire tension, wire offset, spark gap and pulse peak voltage, servo voltage, flushing pressure as constant process parameters. After machining, Scanned Electron Microscopy (SEM) was performed on machined work piece samples to study microstructure. It was concluded that thicker recast layer results through higher pulse ON time setting. The wire deposition on machined surface was lower when using lower pulse ON time and higher pulse OFF time settings [17]. S. Ramesh et. al. contributed an effort to obtain maximum surface finish in WEDM dealing with multi cutting passes while machining Metal Matrix Composite (MMC) work piece. 4-Axis CNC-WEDM machine by Steer Corporation was used to perform experiments using Molybdenum wire as tool electrode material of diameter 0.18mm. White layer or recast layer and heat affected zone (HAZ) on the surface of machined work piece was analyzed by using Field Emission Scanning Electron Microscopy (FESEM). After study the experimental results, it was concluded that with increment in the number of cutting passes value of surface roughness (Ra) reduced. In rough cut pass, surface cracks and craters increased because of formation of White layer, while white layer was reduced in semi-finished cutting passes due to which surface cracks and craters decreased. White layer was completely removed in finish cutting passes [18].G. Sachdevaet.al. proposed study of metal cutting rely on the features of tools, input work materials and machine parameter settings effecting process efficiency and output quality characteristics by taking vital WEDM process parameters namely current, pulse ON time, pulse OFF time, wire speed and wire tension. Work piece electrode and tool electrode were selected as H-21 die tool steel and zinc coated brass wire respectively. Taguchi's L18 orthogonal array technique has been used to evaluate optimal parameter combination to obtain optimal cutting speed, minimum surface roughness value and minimum die width; along with S/N ratio and ANOVA for analysis of selected experiments. It was concluded from experiments that for continuous quality improvement and higher machining efficiency Taguchi's L18 orthogonal array technique was prominent method to predict optimal parameter values [19]. M. Durairajet.al. used the Grey relational theory and Taguchi optimization technique, for optimization of the cutting parameters in Wire EDM for SS304. The aim of optimization was to attain the minimum kerf width and the best surface integrity individually. Stainless steel 304 was employed as work piece; brass wire of 0.25mm diameter was selected as tool along with distilled water which was used as dielectric fluid. Taguchi's L_{16}, orthogonal array technique was used for experiments. The input parameters such as gap voltage, wire feed, pulse on time, and pulse off time were selected for optimization. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length were categorized as fixed parameters. In experiments surface roughness was determined by using contact type surf coder and kerf width was determined through video measuring system. Through multi objective optimization technique grey relational theory, the optimized value was obtained for surface roughness and kerf width and through Taguchi optimization technique; optimized value was obtained individually [20]. P. Gupta et. al. observed the effect of parameters on kerf width in WEDM for HSLA as work piece. It was found that kerf width decreases with increase in pulse ON time, pulse OFF time, spark gap voltage and peak current. Kerf width increases with increase in wire tension. To investigate the effect of selected process parameters, the response surface methodology (RSM) was used to form correlations and mathematical model for the independent process parameters through desired kerf width. The central composite rotatable design was employed for execution of the experiments. The analysis of results concluded that the spark gap voltage, pulse on time, peak current and pulse off time have individually prominent effects on kerf width [21]. V. Muthuramanet. al. investigated effects of different process parameters Pulse ON time, Pulse OFF time, Ignition current, Wire feed and Dielectric pressure on surface roughness. The input parameters were taken as Pulse ON time, Pulse OFF time, Ignition current, Wire feed and Dielectric pressure for investigation of their effect on surface integrity.Design of Experiment was used to study influence of Process variables on WEDM using Tungsten Carbide Cobalt Metal Matrix Composite as work piece. It was suggested that through increase in Pulse ON time, Wire feed, the value of surface roughness increases but when increase in dielectric pressure occur then surface roughness decreases [22]. V.S. Gadakhet. al. investigated the applications of TOPSIS (Technique of order preference similarity to ideal solution) in solving multi-criteria optimization problems for Wire Electrical Discharge Machining. Results obtained by this technique were corresponding to the result obtained through past researchers work. Gap voltage, Pulse on time, Pulse off time and Wire feed were selected as Input parameters. TOPSIS was used for Optimization of Multi performance characteristics like MRR and kerf width. The suggested methodology can be employed for any type of selection problem involving any number of selection criterions [23].J.R. Mevadaet. al. investigated the wire wear rate with relation to separate machining parameters such as peak current, pulse ON/OFF time through factorial design of experiment. EN-8 material was used as work piece and molybdenum wire of 0.18 mm was selected as tool material for the experiments. The effect of peak current, pulse ON/OFF time on wire wear was analyzed through ANOVA. It was concluded that wire wear increases with increase peak current and pulse ON time. Also, it was found that wire wear was not much affected with pulse OFF time [24]. D.S. Kumar et.al. evaluated performance of WEDM parameter (Surface Roughness) while using Al6063/Sicp composite as work piece. Experiments suggested selection of 4 process parameters (Pulse on time, Pulse off time, gap voltage, wire feed) as input parameters. Sic was mixed in 5%, 10% & 15% different proportions in Aluminum through stir casting method and then machining of pure Al 6063 and Al MMC was done. It was found that Surface Roughness (Ra) increases on provided increment in percentage fraction of Sic particles in MMC. Another result so found was relative importance of process parameters which were Pulse off time, Wire feed, Pulse on time and Voltage for surface roughness in WEDM process [25]. V. Parasharet.al. investigated kerf width for WEDM with Stainless Steel grade 304L as workpiece material & CNC Ezeecut WEDM machine was used for execution of experiments. Tool electrode is selected of Brass wire of 0.25 mm diameter. The variables affecting the kerf width were determined through Analysis of variance (ANOVA) technique. It was concluded that Pulse ON time & dielectric flushing pressure has prominent effect on kerf width while Pulse OFF time, wire feed, Gap voltage were less substantial [26]. V.M. Kumaret. al. demonstrated optimization of parameters of WEDM process with Incoloy800 super alloy regarding multiple performance characteristics such as Material Removal Rate (MRR), surface roughness and Kerf width with reference to Grey–Taguchi Method based analysis.Gap Voltage, Pulse On-time, Pulse Off-time and Wire Feed were considered as process parameters. Taguchi's L9 Orthogonal Array is used for conducting experiments. Optimized values of process parameters were determined using Grey RelationalAnalysis and the other prominent parameters were determined by Analysis of Variance ANOVA. Mathematical model was constructed by using non-linear regression analysis with variation of output responses with process parameters method and thus checked for significance. It was concluded that mathematical models can predict the output responses with substantial accuracy [27]. T. R. Newton et. al. determined the main EDM parameters which contribute in formation of recast layer of Inconel 718. It was concluded that average recast layer thickness increased primarily with energy per spark, peak discharge current, and current pulse duration. Over the range of parameters tested, the recast layer was observed to be between 5- 9 min average thickness, although highly variable in nature. The bulk material was inferior to recast material with reference of in-plane tensile residual stresses, as well as hardness and elastic modulus [28]. M. A. Hassan et. al. investigated AISI 4140 steel for the effects on surface integrity in WEDM. Scanning Electron Microscopy (SEM) was used to analyze surface texture of AISI steel through the experiments. Sodick 200 WEDM was used in experiments. 200Brass wire of (0.1-0.33mm diameter) was selected as electrode material. Taguchi orthogonal array L9 was used to design the experiment. The results indicate that Pulse on duration has prominent affect in determining surface texture as compared to Pulsed current. It was also determined by SEM and calculations that value of surface roughness, micro voids, cracks increases as the high discharge energy promote larger melting of work surface and thus deeper formation of crater takes place on work piece surface and due to this surface finish of work piece become irregular [29]. H. Singh et. al. provided the effect of various input parameters of WEDM on MRR. The Hot die steel (H11) was used as work piece material, and brass wire was used as electrode wire. The experiments were done on Electronica sprint cut WEDM machine. Six input parameters such as Pulse ON time, Pulse OFF time, servo voltage, peak current, wire feed & wire tension were investigated individually, keeping other parameter fixed at specified value. It was concluded that the MRR increases with increase in Pulse ON time and Peak current and wherever wire feed and Wire tension produce no substantial effect on MRR [30]. F. Han et. al. evaluated the effect of input parameters like Pulse-duration, Discharge current, Polarity effect, Material & dielectric on Surface Roughness. WEDM machine used was EU64 in the experiments. Brass wire with 0.2mm diameter was used as tool electrode while & alloy steel (Cr12) was employed for work piece. It was determined that Surface roughness was improved by reducing both pulse duration and discharge current with other process parameters remained fixed at certain values. Also, short duration with high peak current value can be suggested for better surface roughness. It was determined that surface roughness can be improved considerably on using reverse polarity machining with proper pulse energy [31].S.S. Mahapatraet. al. proposed the outlines of the development of a model and the application of this model in optimization of WEDM machining parameters. Experiments were conducted to test the developed model and to analyze the results so produced. Pulse ON time, pulse OFF time, discharge current, wire feed, wire tension and dielectric flow rate were employed as process parameters. D2 tool steel was selected for carrying out the experiments. Robofil 100 high precision five axis CNC WEDM was elected for performing experiments. Optimized machining parameters for maximum

MRR and SF in WEDM were determined through Taguchi method [32].A. Hasçalyket. al. investigated the machining characteristics of AISI D5 tool steel in WEDM process. Open circuit voltage, pulse duration, wire speed and dielectric fluid pressure were taken as input Parameters and were changed to determine their effect on the surface roughness and metallurgical structure of work piece. Sodick A320D/EX21 WEDM machine was elected for performing the experiments. Optical and scanning electron microscopy, surface roughness and micro hardness tests were employed to analyze the characteristics of the work piece. It was concluded that the intensity of the process energy affects the amount of recast and surface roughness as well as micro cracking, while the wire speed and dielectric fluid pressure were not having substantial effect [33].

II. CONCLUSION

Performance of WEDM process is based onthe effect of cutting process parameters on performance measures (MRR, WWR, Kerf width and SR). In WEDM, to cut complex and small parts with greater accuracy, proper selection and optimization of process parameters is required to increase the productivity.

A. From the above literature review

1) It is concluded that in most of the cases on increasing Pulse ON time & Peak current, MRR increases and with increase in pulse OFF time & servo voltage, MRR decreases. It is also revealed that diffused wire gives more MRR than simple brass or copper wires.
2) SR increases with increase in pulse OFF time & peak current while decreases with increasing pulse ON time mostly. Better surface finish occurred in trim cut as compared to rough cut.
3) It is found that kerf width decreases with increase in pulse ON time, pulse OFF time, spark gap voltage and peak current. Kerf width increases with increase in wire tension.
4) It is concluded that WWR increases with increase in peak current & pulse ON time while WWR is low when wire tension is high. Also, it is found that WWR is not much affected with pulse OFF time.
5) It is revealed that Taguchi design approach is most reliable and effective technique for the design and optimization of WEDM cutting process parameters among all techniques.

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