# A Review on optimization techniques and Effect of WEDM input parameters on output parameters

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**Abstract - WEDM has changed the scenario of machining in the field of tool industry, aerospace, dies, moulds and counter cutting. WEDM is based on the principle of removal of material through electro erosion. This is a hybrid methodology which has overcome all the complex issues faced by the conventional machining processes. WEDM provides high material removal rate and good surface finishing with low tool wear rate so, this machining method is adapted by the manufacturing industries for machining of challenging jobs. The performance of the WEDM is estimated by the parameters such MRR, WWR, SR and kerf width. The objective of this paper is to analyse the influence of input parameters such as $T_{ON}$, $T_{OFF}$, $I_P$, V, $W_T$ and WF on performance parameters. We have reviewed different types of optimization and analysis techniques such as Taguchi design approach, GRA, PSO, ANN, RSM and ANOVA are used by the researchers. It is concluded that Taguchi's method and ANOVA are most frequently used optimization techniques. MRR is mostly influenced by the parameters $T_{ON}$, $T_{OFF}$, $W_T$, $I_P$ and V as compared to other input parameters of WEDM.**

**Keywords: Process optimization, MRR, SR, Taguchi method, WEDM.**

## I. INTRODUCTION

Wire electric discharge machining (WEDM) has made drastic development in manufacturing industry in terms of accuracy, efficiency, quality and income. Materials science has developed new materials which are in demand because of their invincible properties like lightweight combined with toughness, durability and strength. Often these materials cause considerable difficulties. Conventional machining methods were not capable of such types of advanced machining efficiently Hence, un-conventional machining methods were developed including WEDM [1]. WEDM is a type of EDM method for removal of material from the workpiece surface. The only difference between WEDM and EDM process is the type of tool being employed .In the EDM machining process the symmetry of the tool electrode will be the replication of workpiece but in case of WEDM a thin wire is used as tool electrode [2]. WEDM is an automated machining process by which a conductive material is cut by means of a thin wire electrode which follows a CNC controlled path. WEDM has a moveable worktable which is used for holding the workpiece and to provide motion along X-and Y-axis. The movement of worktable is required to obtain desired geometry of the work material [3]. The wire is rolled through a pair of tensioning roller (known as wire spool). The moving wire electrode continuously fed from wire feed spool and used wire after machining collected by wire take up wheel. The wire is sustained underneath tension between the pair of wire guides placed at the adverse sides of the work material .Machining on WEDM is initiated by drilling hole on the workpiece or starting from the edge. In WEDM process the removal of material is only possible because of vaporization and melting in the existence of dielectric fluid .Workpiece and the tool electrode are conductive materials, both are submerged in a continuously flowing pressurized dielectric fluid (deionized water). The dielectric fluid serves two purposes, it acts as an insulator till a threshold voltage is reached and also acts as a cooling medium. It also flushes off the debris from the machining zone [4]. WEDM machining principal is based on spark erosion process in which the electrical energy converted into thermal energy in the presence of dielectric fluid .Material removal takes place by continuous discrete discharges of sparks between the tool electrode and work material in the presence of fluid. The fluid is ionized in between the tool and workpiece gap there by creating a path for each discharge. The space where discharge occurs gets heated to high scale of temperature. The temperature range we obtained is greater than the melting point of the workpiece, results in

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the melting of work surface. After the erosion, the eroded particle (debris) has been flushed away from the cutting surface. There is no involvement of mechanical forces in this machining process because of the absence of physical cutting forces between charged wire (tool) and workpiece. The erosion of metal is possible due to these sparks. Easily machining of complex geometries (2D & 3D) with higher strength, hardness and toughness, is the main advantage of WEDM [5].

## II. LITERATURE SURVEY

**Sharma P. et Al. (2017)** used Taguchi design approach with Grey relational analysis (GRA) for robust design while machining Inconel 706 .The design was used for optimization of input parameters (pulse on time ($T_{ON}$), pulse off time ( $T_{OFF}$), servo voltage (V) and wire feed (WF) on output parameters (material removal rate (MRR) and surface roughness (SR)). For experimentation, they used a 0.25 mm diametric zinc coated brass wire as tool electrode. For investigation they used Electronic Ecocut CNC wire cut electronic discharge machine (WEDM). Analysis of variance (ANOVA) and Principal Component Analysis (PCA) were used for the analysis of experiment results. After analysis of experimental results, they found that Ton and Toff are significant process parameters on MRR and SR .They calculated the optimized values (Ton-105µs, V- 32v, WF- 4m/min and $T_{off}$ - 27µs) of process parameters on WEDM for better and efficient machining [6].

**Mouralova KA. et Al. (2016)** experimented on MAKINO EU 61 WEDM CNC Machine to study the comparison between four types of workpiece as titanium alloy (Ti-6Al-4V) with two types of heat treated processes and a thermally untreated workpiece of titanium alloy and iron-rhodium alloy on output parameter of surface roughness whereas input parameters were Ton, Toff, WF, $I_P$ (Peak current) and V (Spark gap set voltage) .They used penta cut E brass wire with diameter 0.25mm as tool electrode. Analysis on surface roughness of the work pieces was done by FIB (focused ion beam fabrication) and surface morphology approach. After analysing the results they found that only untreated Titanium alloy among the four workpiece materials had no sign of Globules [7].

**Sharma H. et Al. (2016)** provided an examination on outcome and optimization of input parameters for output parameters Cutting speed, Kerf width and SR in WEDM using H21 die tool steel as work piece material. Tungsten wire was used as tool electrode for this work. Taguchi's L18 orthogonal array was used for design of experiments. Discharge current, $T_{ON}$, $T_{OFF}$, WF and WT (Wire tension) was used as input process parameters. After analysis and optimization of experiments results, it was found that the average cutting speed was mostly affected by $T_{ON}$, $T_{OFF}$ and WF during the rough cut and SR was not affected by any selected factor. Kerf width was mostly affected by discharge current, $T_{ON}$, $T_{OFF}$ and WF during ruff cut [8].

**Choudhuri B. et Al. (2016)** reported the influence of process parameters ($T_{ON}$, $T_{OFF}$, $I_P$, V and WT) on performance parameters (cutting speed and kerf width) for optimization. H21 tool steel was used as workpiece and Soft brass wire (0.25 mm diameter) as tool electrode on Elektra Sprintcut CNC WEDM. For this investigation, Experiments were designed by central composite design technique (CCD) and total number of experiments that were performed is 47. For optimization and analysis of experimental results two methodologies viz. RSM and ANN (artificial neural network modelling), particle swarm optimization (PSO) was used throughout. After optimization and analysis of experimental results, they concluded that ANN- particle swarm optimization (PSO) hybrid methodology is ideal technique than RSM and better alternative of RSM because of its optimal level of optimization of WEDM process parameters [9].

**Goswami A. et Al. (2016)** had performed experiment on Electronica Sprintcut (Electra Elplus 40A DLX) CNC to examine the influence of input parameters like $T_{ON}$, $T_{OFF}$, $I_P$ and wire off-set ($W_O$) on performance parameters i.e. MRR, SR and WWR. For the experiment they used Nimonic 80A alloy as Cutting material and Brass wire (diameter 0.25 mm) as a tool electrode. L27 orthogonal array of Taguchi methodology was applied for design of experiments. For analysis and optimization ANOVA and GRA techniques were used .After optimization and analysis of experimental results, they found that $T_{ON}$ is the most significant parameter for MRR and SR. During trim cut machining it is also revealed that trim cut machining is compatible with high value of surface finish [10].

**Rajmohan K. et Al. (2016)** used Taguchi technique of L27 orthogonal array to examine the major influencing factors that affect the performance parameters MRR, SR and kerf width whereas the process parameters was $T_{ON}$, bed travel speed .For experimentation they used molybdenum wire with diameter of 0.18 mm and 2205 DSS alloy as workpiece material on EDM DK 7744 WEDM machine. ANOVA was used for analysis of experimental result. After analysis of experimental results, they found that $T_{ON}$ is influential process parameter on SR and Kerf. They also concluded that value of SR and kerf width decreased with the increases in the level of $T_{ON}$ [11].

**Mandal A. et Al. (2015)** researched on WEDM for process parameters like as $T_{ON}$, $T_{OFF}$, WF, WT, V and water pressure (WP) on performance parameters like as MRR, SR and Wire wear ratio (WWR). For experimentation, they used zinc coated brass wire of diameter 0.25 mm and Nimonic C-263 alloy as workpiece material on Electra Maxicut 7348 CNC machine. Response surface methodology (RSM) was used for design of experiments and optimization. ANOVA was used for analysis of

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experimental results. After optimization and analysis of experimental results, they found that Ton, Toff, V and WF are influenced process parameters on MRR. Ton, Toff and V are significant parameters on WWR and Toff is influenced process parameter on SR [12].

**Bobbili R. et Al. (2015)** explored the effect of WEDM operation parameters (Ton, Toff, $I_P$ and V ) on performance parameters (MRR, SR and Gap current) .They Used L18 Orthogonal array of Taguchi design approach for design of experiments. ANOVA and GRA techniques were used for analysis of results .For the experiments, they used Al-Mg-Si based alloy grade 6063 as a cutting material on WEDM. After analysis of experimental results, they found that Ton, $I_P$, V are the most significant variable on performance parameters of WEDM and they also concluded that performance parameters were improved by employing GRA technique [13].

**Chinnadurai T. et Al. (2015)** studied on CNC WEDM for high MRR by using two tool electrode wires one is uncoated brass wire and another is zinc coated brass wire, both of the wires having same diameter (0.25mm). $T_{ON}$, $T_{OFF}$, $I_P$, V, WF, WT and SF were selected as Process parameters. For this study, they used AISI 4140 as a work piece material on WEDM. Taguchi L18 full factorial orthogonal array had been selected for design of experiments, and analysis of experimental results was done by using ANOVA. After optimization and analysis of experiments results, they found that Ton is most significant parameter on MRR for uncoated brass wire and for coated brass wire Ton, Toff and V was the significant parameters on MRR. They also concluded that the zinc coated brass tool electrode had given superior results, as comparable to the uncoated brass electrode wire [14].

**Aggarwal V. et Al. (2015)** explored the effect of input parameters such as $T_{ON}$, $T_{OFF}$, $I_P$, V, $W_F$ and $W_T$ on output parameters MRR and SR. For experimentation, they used zinc coated brass wire (0.25 mm diameter) as tool electrode and Inconel 718 as a cutting material on Electra Sprintcut CNC WEDM. Response surface methodology (RSM) was used for design of experiments, and ANOVA was used for analysis of the experimental results. After analysis the results, it was found that $T_{ON}$ was the highly affected parameter on MRR. $T_{ON}$ and V were highly influencing on SR [15].

**Sivaraman B. et Al. (2015)** studied the effect on MRR and SR by using working input parameters like dielectric pressure, gap voltage, table feed, $T_{ON}$, $T_{OFF}$ and $W_T$. For experimentation, they used titanium material as a workpiece. By using Taguchi design approach L18 orthogonal array has been selected for the experimental work and ANOVA selected for the optimization and analysis the experimental results. After optimization and analysis was concluded that the Taguchi method is the most suitable and ideal method for optimization of parameters of WEDM [16].

**Cao C. et Al. (2014)** described the better surface integrity of S390 as compared to SKD11 under different cutting passes (trim cut one to fourth) on WEDM by using process parameters $T_{ON}$, $T_{OFF}$, $I_P$, $W_P$, $W_T$, $W_F$, Wire speed ($W_S$) and wire offset. For experimentation, they used tool steel S390 and SKD11 as a workpiece and zinc coated brass wire 0.25mm diameter as a tool electrode [17].

**Goswami A. et Al. (2014)** examined the input parameters such as $T_{ON}$, $T_{OFF}$, $I_P$, V, WT and WF on output parameters such as MRR, SR and WWR of WEDM. For experimentation, they used brass wire with diameter 0.25 mm as a tool electrode and Nimonic-80A as workpiece on electronica Sprint cut Electra Elplus 40A DLX CNC wire cut EDM. For design of experiments they selected L27 orthogonal array from Taguchi design approach and GRA. For analysis and optimization of experimental results ANOVA and concluded that $T_{ON}$ and $T_{OFF}$ were the most significant factors for MRR, all the factors were significant for WWR it was also observed that high discharge energy forms crater (deep and large) at microstructure level of workpiece [18].

**Khan N. et. Al. (2014)** machined the high strength low alloyed steel (ASTM A572-grade 50) on the process parameters ($T_{ON}$, $T_{OFF}$, $I_P$) and on the performance parameter (Surface integrity (SR) and micro hardness). Machine used for experimentation was DK7712 NC WEDM. By using Taguchi design approach L9 orthogonal array has been selected for the experimental work. ANOVA and GRA techniques were used for analysis and optimization of experimental results and they found that the value of SR increased with increases in the level of $T_{ON}$ and value of SR increased with increases in the level of $I_P$. Analysis of experimental results through ANOVA, they found that the $T_{OFF}$ is most significant factor on Surface integrity [19].

**Goswami A. et Al. (2014)** explored the effect of process parameters on performance parameters. For this investigation, the selected process parameters were $T_{ON}$, $T_{OFF}$, V, $I_P$, WF and WT. Performance parameters were MRR and SR. He had selected Nimonic 80A as a workpiece material and soft brass wire (0.25mm) as a tool electrode. Electronica Sprintcut Electra Elplus 40A DLX CNC WEDM was used for experimentation. L27 orthogonal array was used for design of experiments. Utility concept, Single & Multi response techniques are used for optimization and ANOVA was used as analysis Techniques. After optimization and analysis of experimental results, he found that the $T_{ON}$ and $T_{OFF}$ are highly significant process parameters on MRR. Ton and V are highly significant process parameter on SR but other process parameters were less significant on both performance parameters. He also concluded that for

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considering optimal level of process parameters for both performance parameters of WEDM, single response optimization method provide better results as compared to multi response optimization method [20].

**Nourbakhsh F. et Al. (2013)** described the effect of WEDM process parameters like as pulse width, time between two pulses, servo reference mean voltage, strike pulse current, injection pressure, wire tension and peak voltage on cutting speed, surface integrity and wire rupture by comparing the two wires. The influence of zinc coated brass wire was compared with high speed brass wire. Experiment was performed on Charmilles model 2020 WEDM, they used titanium alloy (TI6AL4v) as a workpiece material and two type of wire electrode (high speed brass and zinc coated brass wire) each of 0.25 mm diameter. The experiments were designed based on Taguchi L18 orthogonal array and ANOVA was used for analysis. After optimization and analysis of experiments results, they found that the zinc coated brass wire resulted higher cutting speed and smother surface finishing as compared to the high-speed brass wire [21].

**Sachdeva G. et Al. (2013)** performed experimental investigation on Electronica Sprintcut CNC WEDM. H21 die tool steel was used as workpiece for the experiment. The tool electrode used for the experiment was zinc coated brass wire (0.25mm diameter). The input parameters were taken as Ton, Toff, WF, WT, $I_P$ on output parameters cutting speed, die width and SR. L18 mixed level orthogonal array of Taguchi's design methodology used for the design of the experiments. For the analysis and optimization of experimental results ANOVA technique was used. After optimization and analysis of experimental results it was found that $I_P$ &Ton are the most significant parameters on die width. , $T_{OFF}$ & $I_P$ are the most significant parameters on SR and, $T_{OFF}$ & $T_{ON}$ are the most significant parameters on cutting speed [22].

**Bobbili R. et Al. (2013)** conducted the experiments on ULTRA CUT WEDM to study the effect of process parameters such as $T_{ON}$, $T_{OFF}$, WT, WF, V and WP on performance parameters such as MRR and SR. For experimentation, they used zinc coated brass wire (.25mm diameter) as tool electrode and high strength armour steel block as workpiece. By using Taguchi design approach, L27 orthogonal array had been selected for design of experiments. For the analysis of experimental results ANOVA technique was used. After optimization and analysis of experiments results, they found that $T_{ON}$, $T_{OFF}$, V are the most significant parameters on both performance parameters and also concluded that optimum setup of process parameters for better performance of CNC WEDM are achieved by applying ANOVA [23].

**Azhiri RB. et Al. (2013)** machined the Al/SiC metal matrix composite on WEDM to investigate the effect of WEDM input parameters (, $T_{ON}$, $T_{OFF}$, , $I_P$, V, WT and WF) on output parameters (cutting velocity (CV), SR). L27 orthogonal array of Taguchi design approach was used for design of experiments design. ANOVA and GRA techniques were used for analysis of experimental result. After analysis of experiment design, they found that the Ton and $I_P$ was the most significant parameters for CV and SR [24].

**Rajyalakshmi G. et Al. (2013)** researched the effect of input parameters on output parameters by applying two different design and analytical approaches i.e. Taguchi design approach and GRA. For this investigation selected input parameters as $T_{ON}$, $T_{OFF}$, V, WF, WT, WP, SF and corner servo and output parameters were MRR, SR and spark gap (SG). Inconel 825 alloy was used as workpiece. Brass wire of 0.25 mm diameter had been used as tool electrode. Ultra Cut 843 CNC WEDM machine was used for machining. L32 mixed orthogonal array of Taguchi's design methodology and GRA was used for the design of experiments. ANOVA technique was used for the analysis. After optimization and analysis of the experimental results they found that the MRR was maximum and SR, SG were minimum while applying Gray-Taguchi approach and also concluded that Gray-Taguchi method is most suitable and ideal for optimization of parameters of WEDM [25].

**Marigoudar N. et Al. (2013)** illustrated a case of optimization of two quality characteristics as MRR and SR while machining a composite of zinc aluminium reinforced material (ZNAL43) with silicon carbide (SiC) on Concord DK7720C 4-axis CNC WEDM .The tool electrode used for machining was molybdenum wire (0.18 mm diameter).The parameters are used in study were $T_{ON}$, $I_P$, $T_{OFF}$, $W_P$, V& $W_T$. $L_{18}$ orthogonal array was selected from Taguchi design approach. After analysis of experimental results, they found that MRR increased with increase in $T_{ON}$ and decreased with increase in $T_{OFF}$. MRR and SR were also increased when the percentage of reinforced material is increased in the composites [26].

**Shandilya P. et Al. (2013)** experimented on Electronica Ecocut CNC WEDM on process parameters $T_{ON}$, $T_{OFF}$, V, on output parameter average cutting speed of WEDM and also present a comparison of optimization and analysis techniques. For experimentation diffused brass wire (0.25 mm diameter) was used as tool electrode and SiCp/6061 Al alloy as a workpiece material. RSM and ANN techniques were used for optimization and analysis of experimental results. After optimization and analysis it was found that V is highly significant process parameter on cutting speed. On the other hand after comparing optimization and analysis techniques they concluded that ANN analytical results were three times better than RSM analytical results [27].

**Yang RT. et Al. (2011)** studied the effect of WEDM input parameters $T_{ON}$, $T_{OFF}$, WP, WT, WF, Servo voltage and Arc off time on performance parameters like MRR, SR and corner deviation (C.D.). For experimentation, they used

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zinc coated brass wire (.25mm diameter) as tool electrode and pure tungsten as workpiece on CW-430F WEDM machine. By using Taguchi design approach, L27 orthogonal array had been selected for design of experiments. RSM, back propagation neutral network (BPNN) and simulated annealing algorithm (SAA) were selected for optimization and analysis of experimental results. After analysis of experimental results they found that MRR increased with the increases in the level of $T_{ON}$. CD decreased with the increases in the level of WT and they also concluded that the BPNN has less percentage of residual as compared to the RSM approach, for conformation results of the optimization input parameters, RSM produced less quality than the BPNN/SAA approach [28].

**Satish KD. et Al. (2011)** described the effect of input parameters such as, $T_{ON}$, $T_{OFF}$, V and WF on output parameters MRR and SR while adding the volume percentage (5-15%) of SiCp with aluminum alloy grade 6065. Negatively polarized brass wire (diameter 0.25mm) was used as tool electrode on 4-axis Electronica Ecocut CNC WEDM. L9 orthogonal Array had been selected for design of experiments through Taguchi design approach and ANOVA for analysis of experiments results. After optimization and analysis of experimental results they found that the V is the most significant factor on the MRR than the other input parameters and also found that value of MRR was decreased and SR increased with increases in volume percentage of SiCp in AL6065 [29].

**Rao P.S. et Al. (2010)** machined Aluminium BIS-24345 on Ultracut 843/F2 CNC WEDM and investigated the effect of input parameters $I_P$, V, $W_T$, $T_{ON}$, $T_{OFF}$, $W_P$ and $W_F$ on output parameter MRR .$L_{18}$ orthogonal array of Taguchi's design methodology was used for design of experiments. After analysis of experimental results by ANOVA, it was found that the process parameters such as $I_P$ is highly significant and $W_F$, $W_T$ are less significant parameters on MRR and $T_{ON}$, $T_{OFF}$, V and $W_P$ had minimal effects on MRR [30].

**Singh H. et Al. (2009)** studied the outcome of numerous input parameters of WEDM on MRR. The Hot worked die steel (H11) was used as workpiece and the brass wire was used as tool electrode wire. The experiments were performed on Electronica sprint cut WEDM machine. Input parameters like as $T_{ON}$, $T_{OFF}$, $I_P$, V, WF and WT on output parameter MRR. Other input parameters were kept fixed at a specified value .From the experimental results they concluded that the MRR increases with increase in $T_{ON}$ & $I_P$, and wherever WF & WT produce no substantial effect on MRR [31].

**Kanlyasiri K. et Al. (2007)** illustrated the effect of input parameters ($T_{ON}$, $T_{OFF}$, $W_T$ and $I_P$) on output parameter (SR). They used zinc coated brass wire of 0.25 mm diameter and DC53 die steel as a workpiece material on Sodick model A280 CNC WEDM. For optimization and analysis they used ANOVA technique. After analysis of experimental results by ANOVA, they found that the parameters $T_{ON}$, $I_P$ are highly affected on SR and also concluded that SR increased while increasing the level of $T_{ON}$ and $I_P$ [32].

**Han F. et Al. (2006)** compared the short and long pulse duration on output parameters MRR and SR whereas the input parameters were $T_{ON}$, $T_{OFF}$, $W_F$ and single pulse energy. They used Cr -12 alloy steel as a workpiece material and 0.20 mm diameter brass wire as a tool electrode. EU 64 WEDM machine was used for experimental work. After optimization and analysis, they found that SR increase with increase in $T_{ON}$, $T_{OFF}$ and discharge current and MRR increased under the short pulse duration as compare to long pulse duration [33].

## III. CONCLUSIONS

From the above literature surveys, it is concluded that WEDM is the best non-conventional machining mechanism for machining of complex geometries with steep hardness and strength. Effect of input parameters on output parameters are given below:

1. MRR is mostly influenced by parameters $T_{ON}$, $T_{OFF}$, $W_T$, $I_P$ and V as compared to other input parameters of WEDM.
2. SR is highly influenced by parameters $T_{ON}$, $T_{OFF}$, $I_P$, V and $W_T$, $W_F$, $S_F$ are the less significant on SR.
3. Cutting speed, Kerf width, EWR are influenced by input parameters $T_{ON}$, $T_{OFF}$, V & $W_F$ than the other parameters.
4. Among all other techniques of optimization Taguchi, GRA, ANN, ANOVA are the ideal and suitable techniques for optimization of parameters also concluded that Taguchi and ANOVA techniques are mostly used for optimization and analysis of parameters.

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