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Review Article

EFFECT OF WEDM PROCESS PARAMETERS ON PERFORMANCE PARAMETERS: A REVIEW

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Wire Electric Discharge Machining (WEDM) process is consummate option for future alternative to face the challenging tasks in material removal and selection of machining parameters. It is necessary to continuously improve WEDM process for enhancing the efficiency and productivity. Dimensional accuracy and high cutting rate is the direct advantage of WEDM. This paper comprises the work performed by various researchers to elaborate the effect of process parameters on performance parameters congregating the optimisation of process parameters with corresponding performance parameters. The Taguchi design approach, Grey Relational Analysis, Response Surface Methodology and ANOVA are used for optimisation of process parameters.

INTRODUCTION

Materials having high hardness and toughness were difficult to machine by traditional machining processes, so non-traditional machining processes were introduced. For machining of complex contours and geometry, WEDM is the best choice. For satisfaction of various requirements in manufacturing field WEDM improved significantly in the present scenario. Due to its electro-thermal process, WEDM has found extreme potential in the field of conductive material machining. WEDM is also helpful for making the dies and tools from high hardened steel across the world. For highest degree of surface finishing and dimensional accuracy on small scale industrial production, WEDM is the best alternative. Wire as a tool electrode has used for machining the material during conversion of electrical energy into thermal energy on WEDM. The electrode wire has diameter 0.15 to 0.30 mm and wire moves through the workpiece for machining. One important thing about WEDM that it doesn't involve any cutting force due to absence of contact between workpiece and charged wire. In WEDM process, electrical energy is produced due to anode cathode operation and spark is produced between wire and workpiece in the presence of dielectric fluid. Wire electrode acts as cathode and workpiece acts as anode. Principle of WEDM is based on spark erosion process, due to this spark electrical energy converted into thermal energy in the presence of dielectric fluid. A pulse generator is used to generate the continuous pulse which is applied between workpiece and moving wire. At very less span of time spark works by which amount of heat increase sharply. The heat generates due to conversion of kinetic energy of electron into heat by which high melting point setup, which is higher than workpiece. This high energy is required to erode the workpiece by using thermal vaporization process [1-4].

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LITERATURE REVIEW

Kulkarni M.L. *et. al*. investigated the effect on material removal rate (MRR), surface roughness (SR) by using process parameters such as pulse on time (T_{ON}), pulse off time(T_{OFF}) peak current (I_P), servo voltage (S_V), wire tension (W_T) and wire feed (W_F). For experimentation, they used titanium grade-5 (Ti-6Al-4V) as a workpiece and 0.25 mm diameter brass wire as a tool electrode on electronica ELPULS-40 CNC WEDM. Taguchi design approach is being selected for experimentation, and Analysis of variance (AVOVA) for analysis the experimental results and found that the optimum values of input parameters for machining of Titanium grade-5 on electronica ELPULS-40 CNC WEDM. For better performance of MRR, taken input parameters values as T_{ON} - 118 µs, T_{OFF} -45 µs, I_P - 210 A, S_V -20 V, W_F -1 and W_T -2 and for SR T_{ON} -110 µs, T_{OFF} -55 µs, I_P -170 A, S_V -40V, W_F -5 and W_T -8 on WEDM [5].

Garg S. *et al*. described the comparison between diffused and brass wire by using input parameters like T_{ON}, T_{OFF} and S_V. For experimentation, they used Stainless steel grade-SS304 as a workpiece and two wires were taken, one is brass wire and another is diffused wire with 0.25mm diameter each on electronica sprintcut WEDM. By using Taguchi design approach, L_9 orthogonal array is being used for the experimentation, and ANOVO for analyse the results. After

analysis of experimental results found that the MRR of diffused wire is more as compare to brass wire. MRR increased with increase in T_{ON}, and MRR decreased with increase in T_{OFF} and S_V [6].

Kumar S. *et. al*. investigated the effect on SR and cutting speed (CS) by using process parameters like T_{ON}, T_{OFF}, I_P, W_F and S_V on 5-axis electronica sprintcut ELPULS-40. For experimentation, they used AISI D2 and wire 0.25mm diameter. By using Taguchi Design approach, L_{18} orthogonal array chose for design of experiments. For analysis the experiment results it is found that the experimental value of surface roughness and cutting speed are 0.85µm and 1.792 mm per minute respectively. For getting the optimal value of CS and SR, Optimal setting of process parameters on WEDM as W_F 8 m/min, I_P-160 A, T_{ON}-118 µs, T_{OFF}-35 µs and S_V-20 V, and W_F 8 m/min, I_P-80 A, T_{ON}-106 µs, T_{OFF}-40 µs and S_V-20 V [7].

Kumar A. *et. al*. investigated the effect on MRR and SR by using process parameter like T_{ON}, T_{OFF}, I_P, and S_V were taken for WEDM process. For experimentation, they used Monal K-500 as a workpiece used on Ultima-IF Wire-cut-EDM. By using Taguchi Design approach, L_{27} orthogonal array is being chosen for the experimentation and Gray relational analysis (GRA) for analysis and optimization the experimental results and found that T_{ON}, T_{OFF}, I_P, and S_V effects on MRR and SR, for optimal multi-characteristic setting optimization had setup some confirmation on WEDM as T_{ON} -123µs, T_{OFF} -50µs, I_P -13A, S_V -30V [8].

Gajjar D. H. *et. al*. studied the effect on MRR, SR and kerf width by using process parameters like T_{ON}, T_{OFF}, and S_V. For experimentation, they used EN-31 tool steel and molybdenum wire 0.25 mm diameter as a tool electrode on electronica sprintcut ELPULS 40 WEDM. By using Taguchi Design approach, L_9 orthogonal array is being chosen for the experimentation and GRA for optimization, analysis the experimental results and found that the MRR, SR and kerf increased with increase in T_{ON}, and MRR is decreases with increase in T_{off} and SR are decreased with increase in S_V and T_{OFF}. S_V is also little effect on kerf width. For optimal multi-characteristic setting optimization setup some confirmation T_{ON} -130 µs, T_{OFF} -30 µs, S_V -30V on WEDM [9].

Aggarwal V. *et. al*. described the effect on MRR and SR by using process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_F and W_T. For experimentation, they used Inconel 718 as a workpiece material and zinc coated brass wire 0.25 mm diameter on Electra sprintcut CNC WEDM. By using RSA for design of experiments, and ANOVA for analysis the experimental results and found that T_{ON} is highly affected parameter on MRR, T_{ON} and S_V are highly affected on SR [10].

Kubade P.R. *et. al*. investigated the effect on MRR, SR and Overcut (OC) by using process parameters like T_{ON}, T_{OFF}, and W_F. For experimentation, they used Titanium diboride (TiB_2) as a workpiece. By using Taguchi Design approach, L_{27} orthogonal array is being chosen for the experimentation and AVOVA for optimization, analysis the experimental results and found that the T_{ON} and T_{OFF} are the highly effected parameters on MRR, T_{OFF} is most effected parameter on SR and OC. For maximum MRR and minimum OC, optimum setting of parameters as like T_{ON}-118 µs, T_{OFF}-48 µs and WF-8 mm/min. For minimum SR, optimum setting of parameters as T_{ON}-112 µs, T_{OFF}-42 µs and W_F-6 mm/min [11].

Sivaraman B. *et. al*. investigated the effect on MRR and SR by using process parameters likedielectric pressure, T_{ON}, T_{OFF} and W_T. For experimentation, they used titanium material as a work piece. Taguchi and ANOVA design approach is being selected for the optimization and analysis the experimental results. After optimisation and analysis they found that improve the multi response characteristics of MRR and SR, shows a decreased value of SR from 3.789µm to 1.687µm and MRR shows increased value of 0.513 g/min to 0.823 g/min [12].

Gogte C. *et.al*. studied the effect on SR by using input parameters T_{ON}, T_{OFF}, I_P and S_V. For experimentation, they used Cryo treated AISI D2 tool steel on sprintcut wirecut EDM. For optimization and analysis used Taguchi design approach and ANOVA, found that the T_{ON} is the mosteffective on SR and T_{OFF} least effective factor on SR and I_P and S_V are affective parameterson SR. Setting the optimum level of process parameters on WEDM as T_{ON}, T_{OFF}, I_P and S_V values 105µs, 50µs, 90A, 45V respectively for Optimal value of SR [13].

Chuanliang Cao *et. al*. have found that the better surface integrity of S390 as compare to SKD11 under different cutting passes (trim cut one to fourth) on WEDM by using input parameters as 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 [14].

Abinesh P. *et. al*. investigated the effect on MRR, SR, Electrode Wear (EWR) by using input parameters as T_{ON}, T_{OFF}, I_P, wire material and workpiece material. For experimentation, they used titanium grade-5 and grade-2 as a workpiece and brass and brass coated wire as a tool electrode. By using Taguchi Design approach, L_{16} orthogonal array chose for the experimentation and ANOVA for analysis the results and found that the maximum MRR, minimum SR, EWR of titanium grade-5 increase with set the value of T_{ON} -120 µs, T_{OFF} -50 µs, I_P -200 A with nickel coated brass wire on WEDM. SR and EWR increase, with increasing in T_{OFF} and I_P. Minimum EWR and maximum MRR of titanium grade-2 as compare to grade-5 [15].

Joshi A. *et. al*. investigated the effect on MRR by using input parameters as T_{ON}, T_{OFF}, I_P, and bed speed. For experimentation, they used EN31 as a workpiece on 4-axis electronica DL-25P CNC machine. Taguchi design approach selected for design of experiments, optimization and analysis, after analysis it is found that the significant setting of process parameters for maximum MRR at level of T_{ON}, T_{OFF}, I_P, bed speed values are 24 µs, 6 µs, 3 A, 35 µm/s respectively on WEDM [16].

Singh J. *et. al*. studied the effect on MRR and SR by using process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_T, W_F. For experimentation, they used P2 tool steel as a workpiece and brass wire 0.25mm diameter as a tool electrode on sprintcut 734 CNC WEDM. By using Taguchi design approach, L9 orthogonal array has been selected for the experiments, after analysis the results it is found that MRR increased with increase in T_{ON} and I_P and decreased with decrease in T_{OFF} and S_V. SR increased with increase in T_{ON}, I_P and W_F and decreased with decreased in T_{OFF}, S_V, W_T [17].

Marigoudar N. *et. al*. investigated the effect on MRR and SR by using process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_T, W_P. For

experimentation, they used zinc aluminium reinforced material with silicon carbide (ZNAL43+SiC) as a workpiece and molybdenum wire 0.18 mm diameter as a tool electrode on Concord DK7720C 4-axis CNC WEDM. By using Taguchi design approach, chose L_{18} orthogonal array. After analysis of experimental results, it is found that MRR increased with increase in T_{ON} and decreased with increase in T_{OFF}. MRR and SR is increased when increase percentage of reinforced material in composite [18].

Singh J. *et. al*. described the effect on MRR and SR by using process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_T, W_F. For experimentation, they used H-13 Hot work tool steel as a workpiece and brass wire 0.25mm diameter as a tool electrode on Electra sprintcut 734 CNC WEDM. By using Taguchi design approach, L_{18}orthogonal array is being chosen for experiments, and after analysis it is found that MRR increased with T_{ON} and I_P and MRR decreased with decrease in T_{OFF} and S_V. SR increased with increase in T_{ON}, I_P and W_F and SR decreased with decrease in T_{OFF}, S_V, W_T [19].

Prajapati S. *et. al*. investigated the effect on MRR, kerf width and SR by using process parameters as T_{ON}, T_{OFF}, S_V, W_T, W_F. For experimentation, they used AISI A2 tool steel as a workpiece machined on Electra sprintcut 734 CNC WEDM. By using Taguchi design approach, L_{27} orthogonal array is being chosen for experimentation, and after analysis the results it is found that the T_{ON} and T_{OFF} are the most effective process parameter for MRR and SR. SV is effective for kerf width [20].

Shah C. *et. al*. studied the effect on MRR by using process parameters as T_{ON}, T_{OFF}, I_P and W_F. For experimentation, they used Inconel 600 as a workpiece material and molybdenum wire 0.18 mm diameter on Concord DK7720C CNC WEDM. By using Taguchi design approach, L_{18} orthogonal array is being choose for experimentation and ANOVA for analysis the experimental results and found that the MRR increased with increase in input parameters are T_{ON} and I_P, and MRR decreased with decrease in T_{OFF} [21].

Patel *et. al*. investigated the effect on MRR and SR by using process parameters as T_{ON}, T_{OFF}, I_P and W_T. For experimentation, they used Stainless Steel grade-304 as a workpiece material and brass wire 0.25 mm diameter on 4-axis Electronica sprintcut CNC WEDM. By using Taguchi design approach, L_9 orthogonal array is being chosen for experimentation and ANOVA for analysis, after analysis the experimental results it is found that the MRR increased with increasing in levels of T_{ON} and I_P. SR decreased with increasing in levels T_{OFF} and I_P [22].

Kumar V. *et. al*. described the effect on CS by using process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_F. For experimentation, they used Nimonic-90 nickel based alloy as a workpiece and copper coated brass wire 0.25 mm diameter as a tool electrode on 5-axis electronica sprintcut ELPUSE-40 CNC WEDM. After optimization and analysis, they found that T_{ON}, T_{OFF} and I_P are most effective input parameters of WDEM on CS [23].

Reddy B.*et. al*. studied the effect on MRR and SR by using process parameters as T_{ON}, T_{OFF}, I_P and bed speed. For experimentation, they used P20 die tool steel as a workpiece material and molybdenum wire 0.18 mm diameter on Concord DK7720C CNC WEDM. By using Taguchi design approach, L_{16} orthogonal array is being choose for experimentation, after analysis the experimental results and found that the MRR increased with increase in process parameters are T_{ON} and I_P, and surface quality is better at low level of T_{OFF} and I_P [24].

Jangra K. *et. al*. investigated the effect on MRR, SR by using process parameters as T_{ON}, I_P, W_T, water pressure (W_P) and taper angle. For experimentation, they used Tungsten carbide-cobalt (WC-Co) composite material as a workpiece and 0.25 mm diameter zinc coated brass wire as a tool electrode on 5-axis electronica sprintcut ELPULS 40 CNC WEDM. By using Taguchi design approach, L_{18}orthogonal array is being chosen for experimentation and GRA for analysis the experimental results.After analysis the results, it is found that the process parameters T_{ON}, T_{OFF} and taper angle is highly significant on MRR and SR [25].

Parashar V. *et. al*. investigated the effect on kerf width by using process parameters as T_{ON}, T_{OFF}, S_V, I_P, W_P and W_F. For experimentation, they used Stainless Steel (Grade-304) as a workpiece material and diffused brass wire having 0.25 mm diameter on Ezeecut pulse WEDM. By using Taguchi design approach is being choose L_{32} orthogonal array for experimentation, and AVOVA for analysis the experiments result. After analysis the results, it is found that during machining the process parameters such as T_{ON}, I_P and W_P are highly effected parameters and S_V, T_{OFF} and W_F are less effected on MRR [26].

Kumar M. *et. al*. described the effect on MRR, SR and kerf width by using process parameters such as T_{ON}, T_{OFF}, S_V and W_F. For experimentation, they used Inconel 800 super alloy as a workpiece and 0.25 mm diameter brass wire as a tool electrode on 4-axis electronica ecocut CNC WEDM. By using Taguchi design approach, L_9orthogonal array is being chosen for experimentation, and GRA for analysis the experiment results and found that the optimum values of input parameters, T_{ON} -10µs, T_{OFF} - 6µs, S_V - 50V, W_F - 8mm/min for the better performance of output parameters on WEDM [27].

Rao P.S. *et. al*. studied the effect on MRR by using process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_T, W_P and W_F. For experimentation, they used Aluminium BIS-24345 as a workpiece material on ultracut 843/F2 CNC WEDM. By using Taguchi design approach is being choose L_{18}orthogonal array for experimentation, and AVOVA for analysis the experimental results and found that the process parameters such as I_P is highly effected and W_F, W_T are less affected on MRR and T_{ON}, T_{OFF}, S_V and W_P are normally affected on MRR [28].

Singh H. *et. al*. investigated the effect on MRR, by using process parameters as T_{ON}, S_V, I_P, W_S, W_T. For experimentation, they used hot die tool steel H-11 as a workpiece and CUZN37 coated brass wire having 0.25 mm diameter on electronica sprintcut CNC WEDM. After optimization and analysis of results found that the MRR is increased with increase in T_{ON} and I_P and MRR decreased with increase in T_{ON} and S_V. W_F and W_T has negligible effect on MRR [29].

Kanlyasiri *et. al*. studied the effect on SR by using process parameters as T_{ON}, T_{OFF}, I_P and W_T. For experimentation, they used DC53 die steel as a workpiece material and zinc coated brass wire 0.25 mm diameter on Sodick model A280 CNC WEDM. After analysis of experimental results by AVOVA, it is found that the input parameters like as T_{ON}, I_P are highly

effected on SR, and SR increased while increase the level of T_{ON} and I_P [30].

Han F. *et. al*. evaluated the effect and compared short and long pulse duration on MRR and SR by using process parameters as T_{ON}, T_{OFF}, W_F and single pulse energy. For experimentation, they used Cr -12 alloy steel as a workpiece material and 0.20 mm diameter brass wire as a tool electrode on EU 64 WEDM. After optimization and analysis of the experiment results, it is found that the MRR increased under a short pulse duration as compare to long pulse duration, and SR increase with increase in T_{ON}, T_{OFF} and discharge current [31].

Hewidy M. S. *et. al*. investigated the effect on MRR, SR and EWR by using process parameters as $T_{ON,}$ T_{OFF}, I_P, W_T, and W_P. For experimentation, they used Inconel 601 as a workpiece material and CuZn377 coated brass wire having 0.25 mm diameter on Electra Maxicut 434 CNC WEDM. For experimentation, they used RSM and conducted 31 no. of experiments and after analysis of experiment results it is found that the MRR is increased with increase in W_P and I_P, SR and EWR are increased with increase in I_P. SR decreased with increase in W_T and Duty factor. Duty factor is combination of T_{ON} and T_{OFF} [32].

Tosun N. *et. al*. described the effect on MRR, kerf width by using process parameters as T_{ON}, S_V, W_S, W_P. For experimentation, they used AISI 4140 tool steel as a workpiece and CUZN37 coated brass wire having diameter 0.25mm Sodick A320D/Ex21 WEDM CNC machine. By using Taguchi design approach, L_{27} orthogonal array is being chosen for experimentation and ANOVA for analysis the experiment results it is found that the T_{ON} and S_V are the most effective and W_S, W_P are less effective parameters on MRR and kerf width. For controlling MRR, kerf S_V is 6 times and 3 times more important than the T_{ON} respectively. S_V are the most significant process parameter on MRR and kerf width [3].

CONCLUSION

From the above literature review it is concluded that WEDM is the best non-traditional machining process while machining complex geometries with enhanced surface integrity. It is important to conclude from above reviews that hardness and strength are no longer dominating factors during machining. Taguchi design approach is reliable and effective technique for the optimization of WEDM parameters. Parameters and their effect on performance parameters are expressed below:-

1. T_{ON}, T_{OFF}, I_P, S_V, $W_{T,}$ W_P are the most effective parameters and S_F, W_f are the least effective parameters on MRR and SR.
2. T_{ON}, I_P, S_V, W_P are the most significant factors for kerf width.
3. T_{OFF}, I_P are the predominant factors for EWR.

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