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Effect and Optimization of cutting process parameters of Hot Work Tool Steel H21

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Abstract- With the evolution of new hard and tough alloys which are difficult to machine with traditional methods, WEDM became one of the most important machining methods. Machining has done with a metal wire which travels in a predetermined path in the presence of a dielectric medium. The paper referred to the optimization of cutting process parameters while cutting hot work tool steel H21 on WEDM. H21 has thermal shock resistance, high toughness along with the ability to withstand high temperatures, so it can be use in different manufacturing industries. By taking T_{off}, T_{on}, S_v and I_p as process parameters, experimental work has been carried out on ELECTRONICA ECOCUT ELPULS 15 WEDM machine to improve performance parameters like SR and MRR. To machine H21 tool steel brass wire (zinc coated) is used. Taguchi's DOE technique is used to optimize process parameters and Regression analysis is used for comparison between predicted and experimental values. By analysis, it was concluded that T_{off} has more effect on MRR and SR than other parameters.

Keywords – Optimization; MRR; SR; tool steel H21; Taguchi.

I. INTRODUCTION

Machining is a process of removing material from given work piece or giving them desired final shape. With the advancement of Mechanical Industries, it became necessary to fabricate/develop new materials having greater toughness, good strength, high hardness and impact resistance. Machining for these kinds of hard materials is difficult through traditional methods. Hence, non-traditional machining techniques developed for the machining of these materials such as WEDM. Cutting forces are absent in WEDM because of absence of direct physical contact between tool and work piece. Also tool wear is negligible and can be used to machine intricate shapes on hard alloys with high accuracy and surface finish. Its main application is to machine dies and molds involved in the production of various components in many industries. Biggest advantage of WEDM is its capability to produce very complex shapes with good accuracy that does not depend on mechanical properties of selected material. Brass, Tungsten, Molybdenum, and Copper can be used as electrode tool wire materials. WEDM works on Thermo-electric theory, in which electrically conductive materials are being cut with a continuous wire electrode. The wire electrode is continuously fed/guides by two wire guides through the work piece. Material removal based on melting and evaporation. Material removal is effected by spark erosion during the passing of wire through the work piece [1] & [2].

In the WEDM process, electrical energy converted into thermal energy, very high temperature produces ranging from 8000 to 12000 ºC at a pulsating DC supply of 20-30 KHz. A small spark gap separates work piece and wire with ample supply of deionized water (dielectric medium). A channel of plasma produced when the voltage applied to the spark gap. When pulsating current passes through this an electric spark produces and metal starts melting due to high temperatures. The wire is fed from the top of the work piece to bottom through wire guides. These guides help to maintain required taper. Pressurized dielectric fluid supplied in the spark gap which is responsible for metal erosion and helps in flushing of eroded debris [2], [3] & [4].

II. LITERATURE REVIEW

H. K. Sharma et al. [5] provides investigation which shows effect and optimization of input parameters for output parameters like Cutting speed, Kerf width, and SR in WEDM using H21 die tool steel as work piece. Tungsten wire is used as tool electrode. This research suggested that average cutting speed was mostly affected by T_{on}, T_{off} and W_F during the ruff cut and SR has not affected by any selected factor. Kerf width was mostly affected by discharge current, T_{on}, T_{off} and W_F during ruff cut.

B. Choudhuri et al. [6] also optimize WEDM process for H21 tool steel for cutting speed and kerf width by using Soft brass wire (0.25 mm diameter). Two methodologies viz. Artificial Neural Network and Response Surface Method compared regarding their modeling, sensitivity analysis and optimization abilities which concluded that the predictability of ANN model is better than RSM which

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emphasize the advantage of ANN in mapping the nonlinear behavior of the system.

B. Sivaraman et al. [7] reveals the effect of various control parameters using Titanium and taking input parameters as Dielectric pressure, T_{on}, T_{off}, W_T, W_F, Gap voltage, and Average gap current. MRR was studied by orthogonal arrays and L9 techniques of Taguchi method. It results in favor of Taguchi method regarding parametric optimization of WEDM on using performance parameters like MRR and SR.

P. Abinesh et al. [8] explain effect of process control parameters on WEDM using Titanium Alloys as work piece. Experiments were carried out using Brass and Brass Coated Nickel wire of diameter 0.15-0.20 mm. Process control parameters like T_{on}, T_{off}, I_P and work piece material were investigated to optimize MRR, SR and Electrode Wear Rate. Taguchi's L16 orthogonal array was selected to optimize process parameters. After optimization and analysis of experimental results, it was concluded that with high values of T_{on}/T_{off} and low values of current MRR increases. When there was an increment in T_{on}, SR decreased and with an increment in T_{off} and I_P SR increased. Electrode wear rate reduced when T_{off} and I_P increased.

A. Goswami et al. [9] in his research surface integrity, MRR and electrode wear was investigated for WEDM process using Nimonic 80A as work piece material. Soft brass wire (0.25 mm) is used as tool electrode to perform experiments. After machining, SEM was performed on machined work piece samples to study microstructure. It concluded that thicker recast layer results through higher T_{on} setting. The wire deposition on the machined surface was lower when using lower T_{on} and higher T_{off} settings.

R. Bobbili et al. [10] describes that how input parameters like as T_{on}, S_V, W_T, T_{off}, W_F and W_P affects MRR and SR. For experimentation, they used high strength armor steel block as cutting material. Brass wire (zinc coated) of dia. 0.25mm taken as tool electrode on CNC ultracut WEDM machine. Taguchi's L27 orthogonal array is used for design of experiments and for analysis of experiments, ANOVA. From experimental results, it was concluded that optimum setup of process parameters for better performance of CNC WEDM are achieved by applying ANOVA and concluded that S_V, Toff, Ton are the considerable input parameters.

Nourbakhsh et al. [11] describes that how different process parameters affects performance parameters like cutting speed, electrode wear and surface integrity by comparing the two wires. For performed experiment, they used TI6AL4v as a cutting material and 0.25 mm diametric brass wires (high-speed and zinc coated) as tool electrodes on Charmilles model 2020 WEDM. Taguchi's L18 orthogonal array is used for design of experiments and for analysis of experiments, ANOVA. From experiments results, it was concluded that as compared to the high-speed brass wire, zinc coated brass wire provides better cutting speed and surface finish.

G. Sachdeva et al. [12] investigates the efficacy of input parameters as Ton, Toff, W_F, W_T and Ip on performance parameters cutting speed, die width and SR. In this investigation H21 die tool steel is cut by using brass wire (zinc coated) on Electronica SPRINTCUT CNC WEDM. By using Taguchi design approach, L18 mixed level orthogonal array selected for experimental work. From experimental results, it was found that Ip & Ton are the most significant parameters on die width, T_{off} & Ip are the most significant parameters on SR and T_{off} & T_{on} are the most significant parameters on cutting speed.

D. S. Kumar et al. [13] explain that how process parameters like Ton, Toff, V and W_F affects MRR and SR while adding the volume percentage (5/10/15%) of SiCp with aluminum alloy grade 6063. Negatively polarized brass wire having diameter 0.25mm used as tool electrode on 4-axis Electronica Ecocut CNC WEDM. Taguchi's L9 orthogonal array is used for design of experiments and for analysis of experiments, ANOVA. From experimental results, they found gap voltage (V) is the most considerable factor on the MRR than the other input parameters and also found the value of MRR is decreased and SR increased with increases the volume percentage of SiCp in Al6063.

H. Singh et al. [14] explains how MRR affected by various input parameters on WEDM by using Hot die steel (H11) material. Brass wire is used as tool electrode and experiments were performed on Electronica sprintcut. Six input parameters [24] such as T_{on}, T_{off}, I_P, W_F, W_T and servo voltage were investigated individually, keeping others fixed. It concluded that if T_{on} and I_P increases then MRR increases, and wherever W_F and W_T produce no substantial effect on MRR.

III. EXPERIMENTAL SET UP

CNC ELECTRONICA ECOCUT ELPULS-15 WEDM is used to perform experiments. In research work, brass wire (zinc coated) having dia. 0.25 mm and H-21 hot-work tool steel as a work piece material is used on WEDM. Tungsten hot-work tool steels also known as type H (H21-H26) steels, are almost same as HSS, but carbon content in these steels is low. When comparing with HSS's, tungsten hot-work tool steels exhibit higher toughness and hot hardness [15] & [16].

Selection of orthogonal array:

(Design of Experiments) DOE helps to determine the minimum possible experiments along with maintaining the required information. One of the main operations of DOE is to determine the value of independent variables and

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these variables help to conduct a finite number of experiments. Taguchi suggested a new improved DOE in which a set of orthogonal arrays is used to design experiments for this purpose. These orthogonal arrays are tables containing numbers and are used to perform experiments. Selected variables grouped into many levels and all the possible combinations then can be taken into account. These considered number of variables and levels help to determine orthogonal arrays in the experiment. Orthogonal arrays may be defined in the form L_A (B^c) [17], [18] & [19].

In this present research work, L_9 (3^4) orthogonal array is used for experimentation. Four input variables with three levels are taken as; T_{on}, T_{off}, I_p and S_v [22]. Table 1 show levels of selected parameters.

Table 1: Selected levels of Parameters

Symbol	Process parameter	Unit	Level 1	Level 2	Level 3
A	T_{on} (pulse ON time)	μsec	123	127	131
B	T_{off} (pulse OFF time)	μsec	40	44	48
C	I_p (peak current)	A	10	11	12
D	S_v (spark gap set voltage)	V	16	20	24

Performance parameters measures:

In this research, MRR and SR are taken as performance parameters. MRR is the removed volume of material in one minute, calculated based on cutting speed (Cs) and its multiplication with dimensions of the work piece [23], numerical representation of MRR is:

$$\mathbf{MRR = Cs \times B \times H}$$

Where, MRR = Material Removal Rate (mm³/min), Cs = Cutting Speed (mm/min), H = Height (mm), B = width (mm).

SR (Surface Roughness) is (vertical) irregularities on real surface which makes it differ from its ideal smooth form. If irregularities are more, the surface is called rough and if less, the surface is called smooth. Mitutoyo Surface Roughness Tester SJ – 201 is used to measure SR [20], [21] & [23].

IV. RESULTS AND DISCUSSION

Table 2 show experimental results of MRR and SR and results are further analyzed by Taguchi and ANOVA. MRR & SR are optimized by using S/N Ratios and means, in the MINITAB-18.

Table 2: MRR and SR Experimental Results

Exp. No.	T_{on}	T_{off}	I_p	S_v	MRR	SNRA1	MEAN1	SR	SNRA2	MEAN2
1	123	40	10	16	17.7	24.96	17.7	2.04	-6.1883	2.039
2	123	44	11	20	16.17	24.174	16.17	2.03	-6.1371	2.027
3	123	48	12	24	15.25	23.665	15.25	2.10	-6.4609	2.104
4	127	40	11	24	16.91	24.563	16.91	2.08	-6.3738	2.083
5	127	44	12	16	16.52	24.36	16.52	2.18	-6.7691	2.18
6	127	48	10	20	16.25	24.217	16.25	2.43	-7.7228	2.433
7	131	40	12	20	17.99	25.101	17.99	1.98	-5.9508	1.984
8	131	44	10	24	17.76	24.989	17.76	2.49	-7.917	2.488
9	131	48	11	16	17.19	24.706	17.19	2.39	-7.568	2.39

Response tables and graphs for MRR

Experimental results of MRR measured by changing four process parameters. Table 3 show different average values of MRR for process parameters at three levels for signal to noise ratio and means data and plotted in figure 1.

In table 4 regression values of ANOVA for MRR are given. In this table, F-value for T_{OFF} is maximum, which shows that T_{OFF} is most significant parameter in the calculation of MRR.

In figure 1 effect of process parameters on MRR is shown, it is clear from figure that T_{OFF} & T_{ON} have higher values of MRR i.e. 17.53 & 17.65 for means respectively and are more significant than I_P and Sv. In table 3 Delta and Rank values also defines the same.

Table 3: Response table for Signal to Noise ratio and means data (Larger is better)

	Signal to Noise ratio				Means Data			
Level	T_{on}	T_{off}	I_p	S_v	T_{on}	T_{off}	I_p	S_v
1	24.27	24.87	24.72	24.68	16.37	17.53	17.24	17.14
2	24.38	24.51	24.48	24.50	16.56	16.82	16.76	16.80

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3	24.93	24.20	24.38	24.41	17.65	16.23	16.59	16.64
Delta	0.67	0.68	0.35	0.27	1.27	1.30	0.65	0.50
Rank	2	1	3	4	2	1	3	4

Table 4: Regression values of ANOVA for MRR

Source	DOF	Adj Sum of Squares	Adj Mean of squares	F-Value	P-Value
Regression	4	5.9838	1.4960	12.57	0.015
T_{on}	1	2.4321	2.4321	20.44	0.011
T_{off}	1	2.5480	2.5480	21.41	0.010
I_P	1	0.6338	0.6338	5.33	0.082
S_V	1	0.3700	0.3700	3.11	0.153
Error	4	0.4759	0.1190		
Total	8	6.4598			

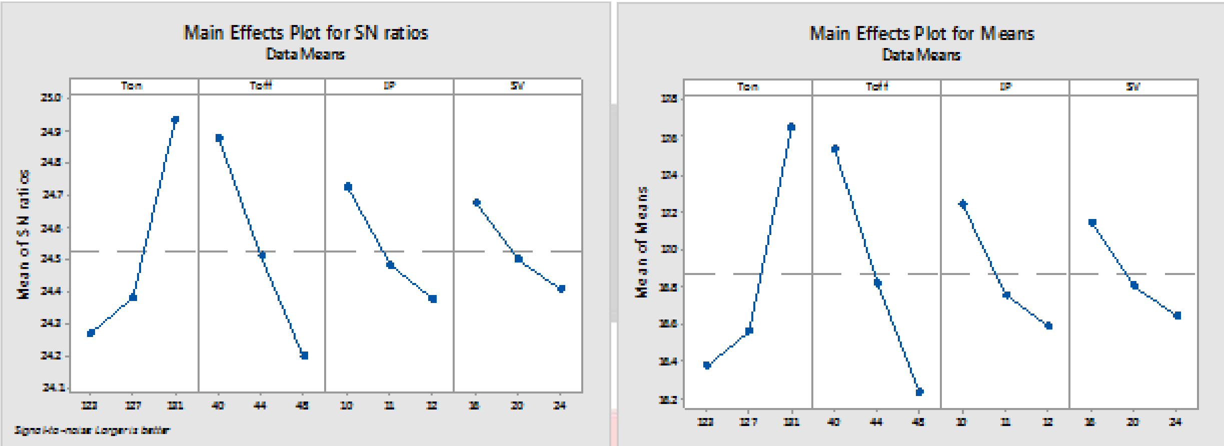

Figure 1: Process Parameter effect on MRR

Response table and graphs for SR

Experimental results of SR measured by changing four process parameters. Table 5 show different average values of SR for process parameters at three levels for signal to noise ratio and means data and plotted in figure 2.

In table 6 regression values of ANOVA for SR are given. In this table, F-value for T_{off} is maximum, which shows that T_{off} is a most significant parameter in the calculation of SR.

In figure 2 effect of process parameters on SR is shown, it is clear from figure that T_{OFF} & T_{ON} have lower values of SR i.e. 2.035 & 2.057 for means respectively and are more significant than I_P and Sv. In table 5 Delta and Rank values also defines the same.

Table 5: Response table for Signal to Noise ratio and means data (Smaller is better)

	Signal to Noise ratio				Means Data			
Level	**T_{on}**	**T_{off}**	**I_p**	**S_v**	**T_{on}**	**T_{off}**	**I_p**	**S_v**
1	-6.262	-6.171	-7.276	-6.842	2.057	2.035	2.320	2.203
2	-6.955	-6.941	-6.693	-6.604	2.232	2.232	2.167	2.148
3	-7.145	-7.251	-6.394	-6.917	2.287	2.309	2.089	2.225
Delta	0.883	1.080	0.882	0.314	0.231	0.274	0.231	0.077
Rank	2	1	3	4	2.5	1	2.5	4

Table 6: Regression values of ANOVA for SR

Source	DOF	Adj Sum of Squares	Adj Mean of squares	F-Value	P-Value
Regression	4	0.272687	0.068172	10.54	0.021
T_{on}	1	0.079811	0.079811	12.34	0.025
T_{off}	1	0.112340	0.112340	17.36	0.014

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I_P	1	0.079811	0.079811	12.34	0.025
S_V	1	0.000726	0.000726	0.11	0.754
Error	4	0.025881	0.006470		
Total	8	0.298568			

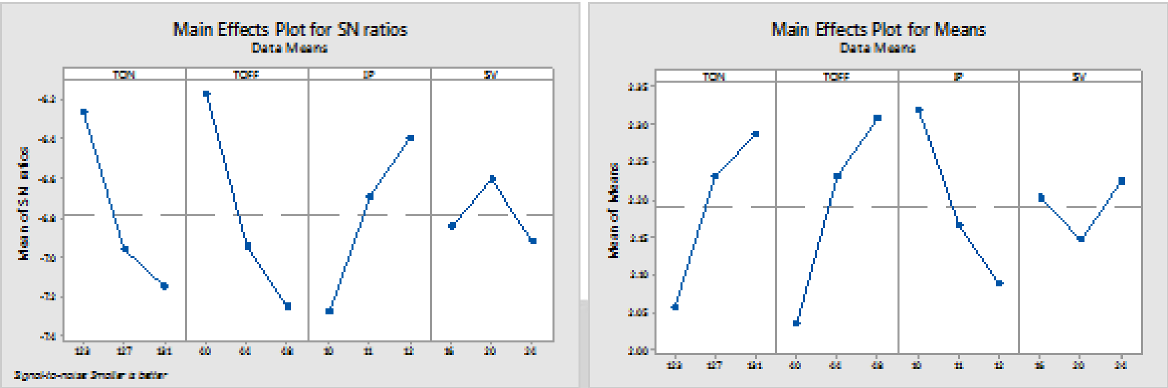

Figure 2: Process Parameter effect on SR

Predicted optimum values at optimum levels of parameters with (Confidence Intervals of Confirmation Experiments) CICE

Optimum levels of significant process parameters help to predict the optimum value of MRR. MRR is "larger is better" performance characteristic and it is clear from figure 1 that the $T_{on}3$, $T_{off}1$, I_P1 and S_V1 provide maximum value of MRR. These levels are $T_{on}3$ = 131 µs, $T_{off}1$ = 40 µs, I_P1 = 10 A and S_V1 = 16 V.

Estimated mean of MRR:

$\mu_{MRR} = \{(T_{on}3 + T_{off}1 + I_P1 + S_V1) - 3(\mu)\}$

µMRR = 18.98 mm³/min

Where, µ = overall mean of MRR

The 95 % CICE is calculated as:

$$\text{CICE} = \sqrt{\left[f\alpha(1,fe)\left\{\frac{1}{\eta eff}+\frac{1}{r}\right\}Ve\right]} = \sqrt{\left[7.71\left\{\frac{1}{1.8}+\frac{1}{1}\right\}0.1190\right]}$$

CICE = 1.20

So the confidence interval is **$17.78 \le \mu_{MRR} \le 20.18$**.

Optimum levels of significant process parameters help to predict the optimum value of SR. SR is "smaller is better" performance characteristic and it is clear from figure 2 that $T_{on}1$, $T_{off}1$, I_P3 and S_V2 provide minimum value of SR. These levels are $T_{on}1$ = 123 µs, $T_{off}1$ = 40 µs, I_P3 = 12 A and S_V2 = 20 V.

Estimated mean of SR:

$\mu SR = \{(T_{on}1 + T_{off}1 + I_P3 + S_V2) - 3(\mu)\}$

µSR = 1.753 micron

Where, µ = overall mean of SR

The 95 % CICE is calculated as:

$$\text{CICE} = \sqrt{\left[f\alpha(1,fe)\left\{\frac{1}{\eta eff}+\frac{1}{r}\right\}Ve\right]} = \sqrt{\left[7.71\left\{\frac{1}{1.8}+\frac{1}{1}\right\}0.00647\right]}$$

CICE = 0.277

So the confidence interval is **$1.476 \le \mu SR \le 2.030$**.

Table 7: Predicted optimum values of MRR & SR

Performance Parameters	Optimum Level	Predicted Optimum Value	CICE
MRR (mm³/min)	$T_{on}3$, $T_{off}1$, I_P1, S_V1	18.98	$17.78 \le \mu_{MRR} \le 20.18$
SR (micron)	$T_{on}1$, $T_{off}1$, I_P3, S_V2	1.753	$1.476 \le \mu SR \le 2.030$

Regression analysis for MRR & SR

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Regression analysis can be used for comparison of predicted and experimental values of performance parameters based on different process parameters.

Regression equation for MRR:

$MRR = 8.63 + 0.1592\ T_{on} - 0.1629\ T_{off} - 0.325\ I_P - 0.0621\ S_V$ …………………… (1)

Regression equation for SR:

$SR = -1.76 + 0.02883\ T_{on} + 0.03421\ T_{off} - 0.1153\ I_P + 0.00275\ S_V$ ……………… (2)

Table 8: Predicted and Experimental values of MRR

Exp. No.	1	2	3	4	5	6	7	8	9
Predicted	17.45	16.23	15.01	17.27	16.79	16.54	17.83	17.58	17.10
Experimental	17.70	16.17	15.25	16.91	16.52	16.25	17.99	17.76	17.19

Table 9: Predicted and Experimental values of SR

Exp. No.	1	2	3	4	5	6	7	8	9
Predicted	2.046	2.078	2.111	2.068	2.067	2.446	2.057	2.435	2.434
Experimental	2.039	2.027	2.104	2.083	2.180	2.433	1.984	2.488	2.390

V. CONCLUSIONS

From the above experimental analysis it is concluded that T_{off} is the most significant factor for both MRR and SR. MRR values are influenced mostly by T_{on}, T_{off}, and I_P. The third level of T_{on} has more effect on MRR. SR values are influenced mostly by I_P, T_{on} and T_{off}. The first level of T_{off} has more effect on SR. Taguchi method is used to optimize MRR and SR. Optimal levels of process input parameters for MRR and SR are (T_{on}3, T_{off}1, I_P1, S_V1) and (T_{on}1, T_{off}1, I_P3, S_V2) respectively. Predicted optimum value for MRR is found to be 18.98 mm³/min at T_{on}3, T_{off}1, I_P1, and S_V1. The 95 % CICE found is $17.78 \leq \mu_{MRR} \leq 20.18$ mm^3/min. Predicted optimum value for SR is found to be 1.753 micron at T_{on}1, T_{off}1, I_P3 and S_V2. The 95 % CICE found is $1.476 \leq \mu SR \leq 2.030$ micron. From regression analysis it is observed that the experimental values of MRR and SR are better than the predicted values.

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