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Multi-Response Optimization of Process Parameters Based On MRSN for D2 Steel Using WEDM Process with Plain Brass Wire and Zinc Coated Brass Wire

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Abstract- Wire Electrical Discharge Machining plays an important role in precision machining. The material removal rate, higher the best and surface finish, lower the best, are mostly required as output response. But it is a well known fact that both can't be achieved simultaneously. In this study multi response signal noise (MRSN) method is used to optimize different process parameters for material removal rate surface roughness using different weightage for both. Hardened D2 steel is used as workpiece because of its high application in industries. The L18 mixed orthogonal array is used to perform experiments and ANOVA is used to find contribution and significance of different process parameters. Plain brass wire and zinc coated wire are used to perform experiments. Confirmatory experiments are performed at optimum levels and percentage error or change is calculated to draw conclusions about design of research.
Keyword-: ANOVA, MRR, SR, MRSN, optimization, coated wires, L18 OA.

I. INTRODUCTION

Wire Electrical Discharge Machining is an operation in which material is eroded by successive electric sparks generated by current supply. Copper, brass, molybdenum etc. conducting materials are used in wire form as tool electrode. Dielectric liquid generally ionized water is used in WEDM [1]. The high heat generation results in melting and vaporizing of the tool and work piece. Heat generated at each electrical spark is around 8000 ^{0}C to 12000 ^{0}C. The WEDM is largely used in manufacturing dies and moulds. The WEDM's CNC system has the capability to control movement of wire and perform machining at high accuracy. The wire diameter ranges from 0.05 to 0.35 mm. The intricate shapes and smaller corner radii can be achievable with very thin wires. There is no mechanical stress induced during machining process as wire does not touch the workpiece. [2]. The WEDM is an exceptional machining process for manufacturing of tough material parts that are highly challenging to machine by traditional machining processes. Mostly, the wires are used only once for machining and discarded after use. [3] According to Liao and Huang [4], feed rate and pulse time on have major impact in material removal and pulse time on has major impact on surface roughness on machining of SKD11 alloy in WEDM. The experiments were operated using Taguchi's L18 mixed array. Ramakrishnan and Karunamoorthy [5] conducted experiments on heat treated D2 steel material with zinc coated brass wire on WEDM. Taguchi's L16 OA was used to perform experiments having five input parameters on machining parameters and results were analyzed by MSRN and ANOVA methods. It has been found that T_{ON} and I_P have influenced more than any other parameters on MRR, SR and wire wear ratio. Mahapatra and Patnaik [6] investigated various interactions between factors and their individual effects on maximization of MRR and surface finish and found that current, pulse on time, dielectric flow rate and their interactions have influenced more than other factors. Dhobe et al. [7] conducted experiments on WEDM on D2 single tempered and double tempered to find effects of input parameters on surface roughness. It was observed Surface roughness rises with rise in T_{on} and I_p, decreases with rise in T_{off} and S_v. It was found that double tempered steel after hardening has less surface roughness compared to single tempered. Mann and Chaudhary [8] investigated the outcomes of four process variables of WEDM on the MRR and surface roughness (R_a). RSM and ANOVA methodology was used to analyze performance parameters and found $T_{on,}$ $T_{off,}$ S_v have maximum influence on MRR and $T_{on,}$ T_{off} have significant effect on R_a and I_p in MRR, S_v in R_a are very less influencing. Ikram et al. [9] conducted experiments for optimization of eight control factors including flush pressure and material thickness to measure their effect on MRR and SR. In case of roughness, T_{on} and open voltage were significant and for kerf T_{on} and WT; and for MRR significant factors were T_{on}, S_v. Material thickness doesn't have significant effect in either case. Patil and Waghmare [10] conducted experiments on Sodick WEDM to examine the conditions for maximum material removal rate (MRR) with the response surface methodology (RSM) approach. The material selected was D2 steel and electrode used was brass wire. RSM approach was applied on three factors viz., pulse time on, peak current and wire tension each at three levels. It was observed that peak current was more significant than pulse on time and wire tension were less significant for material removal rate. Bhatia et al. [11] studied the effect of four process variables on SR in WEDM. D2 steel workpiece was selected with brass wire as electrode. Taguchi's L9 OA was applied to form experimentation design. The process variables were I_P, T_{ON}, T_{OFF} and wire tension (W_T), each at three levels. S/N ratio and ANOVA techniques were used to analyze the data for surface roughness. The results showed that pulse off time has greater contribution in attaining less surface roughness. Optimum parameters were selected from S/N ratio values for lesser surface roughness. Predicted value was calculated for selected parameters and confirmation experiments showed error of 3.93%.

II. MATERIAL AND METHOD

The hardened AISI D2 alloy steel plate of 130mm × 133mm × 10mm size has been used as work piece for experiments. It is a high carbon high chromium alloy tool steel. D2 steel has high wear resistance. It has hardness in the range of 56-62 HR. It acquires mild corrosion resisting properties because of high content of chromium. Its chemical composition properties are as C; 1.52%, Si; 0.37, Mn; 0.40%, P; 0.04%, S; 0.062, Cr; 12%, Mo; 0.56% and V; 0.18%. It has various applications as manufacturing of stamping or forming dies, shear blades and tools. Steel Blank is undergone the vacuum heat treatment process for enhancement of material properties such as hardness. At this process with 6 bar nitrogen gas quenching a cooling speed from austenitising temperature 980^0C to 520^0C of 28^0C/min in the surface was achieved to obtain a hardness of 62 HRC or 748HV1.

Two types of wires are used for experimentation viz. plain brass wire (0.25 mm diameter, Cu 65%, Zn 35%) and zinc coated brass wire (0.25 mm diameter, Cu 65%, Zn 35% and Zinc coating 5 µm). The Brass wire has high tensile strength as well as high electrical conductivity. Copper wires have high conductivity than brass but lesser tensile strength restricts their use in industries due to chances of breakage on high tension. Stratified wire or coated wires can also be used for better machining. According to literature review, very less work has been done by using stratified wires in WEDM process.

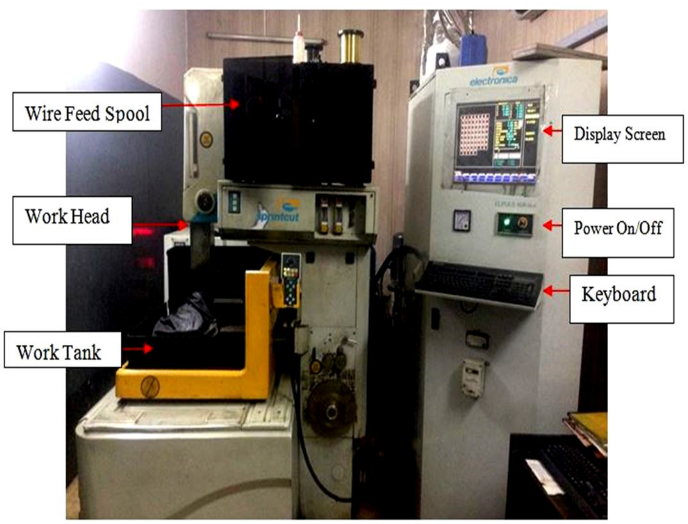

Figure 1: WEDM *[Photo courtesy: Aman Metal Products, Ludhiana]*

The experiments were conducted on Electra Sprintcut 734 WEDM (figure 1). It is a rough cut operation in which both MRR and SR have equal importance. The input parameters are chosen by proper pilot study experimentation on D2 steel by varying individual factor at a time. Taguchi's L18 mixed OA is used for design the experiments layout. Minimum levels for parameters selected are three to find true influence of response parameters. One parameter i.e. peak current (I_P) is varied to six levels to examine its effect for wide range. So that orthogonal array is selected in such a way that OA should have minimum 3 level of factor. The other three factors are varied at three levels each. The levels selected for parameters are described in table 1. Surface Roughness of the machined sample is machined on Surftest SJ-400 and 6 reading are taken and their mean is taken as the final value of surface roughness for each sample Material Removal Rate is calculated according Eq. (1). The kerf width is calculated using Nikon Profile Projector. Cutting speed is obtained from the display screen of WEDM.

$$MRR = C_s \times t_w \times k \tag{1}$$

Where;
MRR= Material Removal Rate (mm^3/min)
C_s=Cutting Speed (mm/min)
t_w=Thickness of workpiece (mm)
k=Kerf Width (mm)

Table 1: Process parameters with level values

Factors	Parameters (Units)	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
I_P	Peak Current (A)	130	150	170	190	210	230
T_{ON}	Pulse on time (µs)	0.6	0.9	1.2	-	-	-
T_{OFF}	Pulse Off Time (µs)	19	26	34	-	-	-
S_V	Spark Gap Set Voltage (V)	20	30	40	-	-	-

The main aim of the present study is to examine the surface topography and performing the multiple response optimization with multi response signal noise (MRSN) method. Multi-objective optimization is method to find out optimum levels of parameters which give desired results for two or more than two machining performance parameters. These levels affect the results of more than one response. In this section, multi-objective optimization is done on two machining performances. As material removal rate and surface roughness are the most desired outputs of any manufacturing process, both have taken for the optimization. To make the optimization economical, equal importance is given to both machining parameters. Multi objective optimization is done using multi response signal noise ratio (MRSN). MRSN is a method designed by Taguchi to optimize multi response characteristics. Since, most of the output response characteristics have different measurement unit and different group in S/N ratio calculations, so it is not possible to perform analysis. MRSN method includes following steps to perform multi objective characterization [Gaitonde et al., 2006].

Step 1- Calculate the loss function (L_{ij}).
For smaller the better, Eq. (2)

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} y_{ijk}^2 \tag{2}$$

For larger is better, Eq. (3)

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} \frac{1}{y_{ijk}^2} \tag{3}$$

where, n is the no. of repeated experiments. (L_{ij}) is loss function of the i^{th} performance characteristic in the j^{th} experiment. Y_{ijk} is the experimental value of the i^{th} performance characterizes in the j^{th} experiment at the k^{th} test.

Step 2- Calculate normalized quality loss i.e. N_{ij} as described in Eq. (4)

$$N_{ij} = \frac{L_{ij}}{L_i^*} \tag{4}$$

Where; $L_i^* = \frac{1}{n}\sum_{i=1}^{n} L_{ij}$

Step 3- Eq. (5) describes the total loss function (TL_j). Weights are applied according to the priority of each normalized loss function. This method defines the importance of every response characteristic.

$$TL_j = \sum_{i=1}^{p} W_i N_{ij}$$

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(5)

Where, *Wi* is the weighting factor, *p* is the total number of quality characteristics.

Step 4- The overall S/N ratio is calculated in this step to perform multi-objective optimization. This overall S/N ratio is known as multiple response S/N ratio (MRSN). The calculation method multiple response S/N ratio (MRSN) is described in Eq. (6):

$$MRSN = -10\log(TL_j) \tag{6}$$

III.RESULTS AND DISCUSSIONS

Table 2 shows the mean values for material removal rate (mm^3/min) and surface roughness (μm) obtained when workpiece is machined with both wires.

Table 2: Result values for MRR & SR (Plain brass and Zinc coated wires)

Run	Plain Brass wire						Zinc Coated Brass wire					
	MRR		SR		Mean		MRR		SR		Mean	
	R1	R2	R1	R2	MRR	SR	R1	R2	R1	R2	MRR	SR
1	4.39	4.46	2.83	2.63	4.43	2.73	4.73	4.93	2.52	2.43	4.83	2.47
2	6.01	5.96	2.91	2.75	5.99	2.83	7.84	7.87	2.52	2.71	7.85	2.61
3	5.91	5.88	2.73	3.13	5.90	2.93	8.10	7.97	2.75	2.76	8.04	2.75
4	4.32	4.39	2.57	2.58	4.36	2.57	5.78	5.91	2.38	2.31	5.84	2.34
5	5.57	5.54	2.73	2.61	5.56	2.67	7.42	7.64	2.54	2.42	7.53	2.48
6	7.49	7.61	3.21	3.28	7.55	3.24	8.46	9.94	3.06	3.02	9.20	3.04
7	3.66	3.72	2.60	2.52	3.69	2.56	4.58	5.07	2.37	2.26	4.82	2.32
8	4.87	4.92	2.39	2.57	4.90	2.48	6.73	7.01	2.43	2.40	6.87	2.41
9	8.75	8.67	3.51	3.15	8.71	3.33	12.16	12.25	3.09	3.11	12.21	3.10
10	2.79	2.82	1.67	1.60	2.81	1.63	3.61	3.64	1.91	1.80	3.63	1.85
11	7.80	7.82	2.94	3.03	7.81	2.99	8.30	8.10	2.53	2.65	8.20	2.59
12	9.13	9.06	3.27	3.26	9.10	3.26	9.45	9.37	2.96	2.91	9.41	2.94
13	3.29	3.31	1.93	1.89	3.30	1.91	4.53	4.64	2.00	1.92	4.58	1.96
14	5.85	5.97	2.66	2.77	5.91	2.71	7.56	7.62	2.50	2.52	7.59	2.51
15	8.56	8.64	3.62	3.18	8.60	3.40	10.72	10.59	3.12	3.09	10.65	3.10
16	3.12	3.17	2.23	2.28	3.15	2.25	4.59	4.47	2.19	2.08	4.53	2.13
17	9.14	9.21	2.84	2.84	9.18	2.84	12.16	12.01	2.51	2.43	12.09	2.47
18	10.03	9.91	3.53	3.45	9.97	3.49	10.44	10.79	2.94	2.98	10.61	2.96

The results obtained by using steps 1 (Eq. 3) and step 2 (Eq. 4) are shown in Table plain brass wire and zinc coated brass wire. The value calculated in Table 3 is used further in calculation for MRSN value in table 4 for plain brass wire and in table 6 for zinc coated brass wire.

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Table 3: MRSN values Plain Brass wire

Run	Plain Brass Wire				Zinc Coated Brass Wire			
	L_{ij}		$N_{ij}=L_{ij}/L_i^*$		L_{ij}		$N_{ij}=L_{ij}/L_i^*$	
	MRR	SR	MRR	SR	MRR	SR	MRR	SR
1	0.051	7.436	1.224	0.935	0.043	6.115	1.735	0.917
2	0.028	8.001	0.669	1.006	0.016	6.821	0.655	1.023
3	0.029	8.625	0.689	1.084	0.015	7.563	0.626	1.134
4	0.053	6.605	1.263	0.830	0.029	5.488	1.185	0.823
5	0.032	7.133	0.776	0.897	0.018	6.142	0.713	0.921
6	0.018	10.515	0.420	1.322	0.012	9.227	0.487	1.383
7	0.073	6.542	1.759	0.823	0.043	5.362	1.750	0.804
8	0.042	6.134	1.000	0.771	0.021	5.820	0.858	0.873
9	0.013	11.106	0.316	1.396	0.007	9.595	0.271	1.439
10	0.127	2.658	3.045	0.334	0.076	3.435	3.071	0.515
11	0.016	8.912	0.393	1.121	0.015	6.712	0.601	1.006
12	0.012	10.644	0.290	1.338	0.011	8.615	0.456	1.292
13	0.092	3.639	2.200	0.458	0.048	3.833	1.925	0.575
14	0.029	8.324	0.686	1.047	0.017	6.288	0.702	0.943
15	0.014	11.590	0.324	1.457	0.009	9.626	0.356	1.443
16	0.101	5.075	2.422	0.638	0.049	4.550	1.973	0.682
17	0.012	8.037	0.285	1.011	0.007	6.103	0.277	0.915
18	0.010	12.182	0.241	1.532	0.009	8.762	0.359	1.314

L_i^* (MRR) =0.042, L_i^* (SR) =7.953 (Plain Brass wire)
L_i^* (MRR) =0.025, L_i^* (SR) =6.670 (Zinc coated brass wire)

Table 4: MRSN values brass wire

Run	W_iN_{ij}		TL_j	MRSN (db)	W_iN_{ij}		TL_j	MRSN (db)	W_iN_{ij}		TL_j	MRSN (db)
	MRR W=5	SR W=5			MRR W=7	SR W=3			MRR W=3	SR W=7		
1	6.118	4.675	10.792	-10.331	8.565	2.805	11.369	-10.557	3.671	6.545	10.215	-10.092
2	3.344	5.030	8.374	-9.229	4.681	3.018	7.699	-8.864	2.006	7.042	9.048	-9.566
3	3.446	5.422	8.869	-9.479	4.825	3.253	8.078	-9.073	2.068	7.591	9.659	-9.849
4	6.316	4.152	10.468	-10.199	8.842	2.491	11.334	-10.544	3.789	5.813	9.603	-9.824
5	3.881	4.484	8.365	-9.225	5.434	2.690	8.124	-9.098	2.329	6.278	8.606	-9.348
6	2.101	6.611	8.712	-9.401	2.942	3.966	6.908	-8.394	1.261	9.255	10.516	-10.218
7	8.797	4.113	12.910	-11.109	12.316	2.468	14.784	-11.698	5.278	5.758	11.037	-10.428
8	4.999	3.856	8.855	-9.472	6.998	2.314	9.312	-9.690	2.999	5.399	8.398	-9.242
9	1.579	6.982	8.561	-9.325	2.210	4.189	6.399	-8.061	0.947	9.775	10.722	-10.303
10	15.223	1.671	16.894	-12.277	21.312	1.003	22.314	-13.486	9.134	2.340	11.473	-10.597
11	1.963	5.603	7.566	-8.789	2.749	3.362	6.111	-7.861	1.178	7.844	9.022	-9.553
12	1.448	6.692	8.140	-9.106	2.027	4.015	6.042	-7.812	0.869	9.368	10.237	-10.102
13	10.998	2.288	13.286	-11.234	15.397	1.373	16.770	-12.245	6.599	3.203	9.802	-9.913
14	3.430	5.233	8.663	-9.377	4.802	3.140	7.942	-8.999	2.058	7.326	9.384	-9.724

15	1.619	7.287	8.906	-9.497	2.267	4.372	6.639	-8.221	0.972	10.201	11.173	-10.482
16	12.110	3.190	15.301	-11.847	16.955	1.914	18.869	-12.757	7.266	4.466	11.733	-10.694
17	1.423	5.053	6.476	-8.113	1.992	3.032	5.024	-7.010	0.854	7.074	7.928	-8.991
18	1.205	7.658	8.863	-9.476	1.687	4.595	6.282	-7.981	0.723	10.722	11.445	-10.586

The factor with p-value less than .05 is counted significant due to 95% confidence level taken during analysis. ANOVA calculations show the percentage contribution of factors variation in case for MRSN plain brass wire (Weightage MRR, W=5, SR, W=5) as T_{on} (76.77%), T_{off} (12.81%) are significant and I_p (2.63%), S_v (0.59%) are the non significant factors, (Weightage MRR, W=7, SR, W=3) as T_{on} (78.68%), T_{off} (14.76%) are significant and I_p (2.13%), S_v (2.06%) are the non significant factors and (Weightage MRR, W=3, SR, W=7) as T_{on} (67.97%) is significant and T_{off} (2.33%) , I_p (5.66%), S_v (5.01%) are the non significant factors. According to delta statistics described in Table 5 ranks are assigned to the factors as per their significance value. The delta value is obtained by subtracting smaller value from the larger value for each factor and ranks are assigned accordingly. Highest delta value got the highest rank. The optimum parameters are selected by selecting levels (marked bold in table 5) having high value of S/N ratio for each parameter from response tables.

Table 5: Delta Statistics table of Response values for MRSN Ratio

LEVELS	Plain Brass wire											
	MRR W=5, SR W=5				MRR W=7, SR W=3				MRR W=3, SR W=7			
	I_P	T_{on}	T_{off}	S_V	I_P	T_{on}	T_{off}	S_V	I_P	T_{on}	T_{off}	S_V
1	-9.68	-11.17	**-9.38**	**-9.75**	-9.50	-11.88	**-8.71**	**-9.25**	-9.84	-10.26	**-9.87**	-10.10
2	-9.97	**-9.03**	-9.90	-9.89	-9.35	-8.59	-9.62	-9.65	**-9.80**	**-9.40**	-9.99	-9.98
3	**-9.61**	-9.38	-10.31	-9.94	-9.82	**-8.26**	-10.40	-9.83	-9.99	-10.26	-10.05	**-9.83**
4	-10.06				-9.72				-10.08			
5	-10.04				-9.82				-10.04			
6	-9.81				**-9.25**				-10.09			
DELTA	0.45	2.13	0.93	0.20	0.57	3.62	1.69	0.58	0.29	0.85	0.17	0.26
Rank	3	1	2	4	4	1	2	3	2	1	4	3

Prediction for MRSN with optimal parameters

The high value for MRSN can be predicted from following equation using optimum levels of parameters. The MRSN values at optimal levels are taken from Table 5. Eq. 7, 8 & 9 describe the calculation for MRSN with plain brass wire at optimal levels for significant factors.

Weightage MRR W=5, SR W=5

$$\alpha_{MRR} = T_{ON\,3} + T_{OFF\,1} - \mu'_{MRSN} \quad (7)$$

$$\alpha_{MRSN} = -8.54 \text{ db}$$

Weightage MRR W=7, SR W=3

$$\alpha_{MRR} = T_{ON\,3} + T_{OFF\,1} - \mu'_{MRSN} \quad (8)$$

$$\alpha_{MRSN} = -7.4 \text{ db}$$

Weightage MRR W=3, SR W=7

$$\alpha_{MRR} = T_{ON\,2} \quad (9)$$

$$\alpha_{MRSN} = -9.40 \text{ db}$$

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Table 6: MRSN values Zinc coated brass wire

Run	W_iN_{ij} MRR W=5	W_iN_{ij} SR W=5	TL_j	MRSN (db)	W_iN_{ij} MRR W=7	W_iN_{ij} SR W=3	TL_j	MRSN (db)	W_iN_{ij} MRR W=3	W_iN_{ij} SR W=7	TL_j	MRSN (db)
1	8.673	4.584	13.257	-11.224	12.142	2.751	14.892	-11.730	5.204	6.418	11.622	-10.653
2	3.276	5.114	8.390	-9.238	4.587	3.068	7.655	-8.839	1.966	7.159	9.125	-9.602
3	3.131	5.669	8.800	-9.445	4.383	3.402	7.784	-8.912	1.878	7.937	9.815	-9.919
4	5.926	4.114	10.041	-10.018	8.297	2.469	10.765	-10.320	3.556	5.760	9.316	-9.692
5	3.564	4.604	8.169	-9.122	4.990	2.763	7.753	-8.895	2.139	6.446	8.585	-9.337
6	2.433	6.917	9.350	-9.708	3.407	4.150	7.557	-8.783	1.460	9.684	11.144	-10.470
7	8.751	4.020	12.771	-11.062	12.252	2.412	14.663	-11.662	5.251	5.628	10.878	-10.366
8	4.291	4.363	8.654	-9.372	6.007	2.618	8.625	-9.358	2.575	6.109	8.683	-9.387
9	1.356	7.193	8.549	-9.319	1.899	4.316	6.214	-7.934	0.814	10.070	10.884	-10.368
10	15.354	2.575	17.929	-12.536	21.495	1.545	23.041	-13.625	9.212	3.605	12.818	-11.078
11	3.007	5.032	8.038	-9.052	4.209	3.019	7.228	-8.590	1.804	7.044	8.848	-9.468
12	2.282	6.458	8.740	-9.415	3.195	3.875	7.070	-8.494	1.369	9.042	10.411	-10.175
13	9.626	2.874	12.499	-10.969	13.476	1.724	15.200	-11.818	5.775	4.023	9.798	-9.912
14	3.508	4.714	8.222	-9.150	4.911	2.828	7.739	-8.887	2.105	6.599	8.704	-9.397
15	1.781	7.216	8.997	-9.541	2.493	4.330	6.823	-8.340	1.068	10.103	11.171	-10.481
16	9.863	3.411	13.274	-11.230	13.808	2.047	15.854	-12.002	5.918	4.776	10.693	-10.291
17	1.384	4.575	5.959	-7.751	1.937	2.745	4.682	-6.704	0.830	6.405	7.235	-8.594
18	1.795	6.569	8.364	-9.224	2.513	3.941	6.454	-8.098	1.077	9.196	10.273	-10.117

ANOVA calculation for zinc coated brass wire shows the contribution of factors for variation for MRSN (Weightage MRR, W=5, SR, W=5) as T_{on} (76.02%) is the only significant factor and other non significant factors are T_{off} (7.93%), I_p (7.09%) and S_v (0.13%), (Weightage MRR, W=7, SR, W=3) as T_{on} (81.03%) and T_{off} (9.37%) are significant factor and other non significant factors are, I_p (5.22%) and S_v (0.05%) and (Weightage MRR, W=3, SR, W=7) as T_{on} (65.14%) is the only significant factor and other non significant factors are T_{off} (2.53%), I_p (9.67%) and S_v (2.25%).

According to delta statistics described in Table 7 ranks are assigned to the factors as per their significance value. The delta value is obtained by subtracting smaller value from the larger value for each factor and ranks are assigned accordingly. Highest delta value got the highest rank. The optimum parameters are selected by selecting levels (marked bold in table 7) having high value of S/N ratio for each parameter from response tables.

Table 7: Response values for MRSN Ratio

Zinc Coated Brass Wire												
LEVELS	MRR W=5, SR W=5				MRR W=7, SR W=3				MRR W=3, SR W=7			
	I_P	T_{on}	T_{off}	S_V	I_P	T_{on}	T_{off}	S_V	I_P	T_{on}	T_{off}	S_V
1	-9.68	-11.17	-9.38	-9.75	-9.83	-11.86	-8.94	-9.63	-9.67	-10.33	-9.88	-10.08
2	-9.61	-9.03	-9.90	-9.89	-9.33	-8.55	-9.63	-9.56	-10.06	-9.30	-9.92	-9.94
3	-9.97	-9.38	-10.31	-9.94	-9.65	-8.43	-10.26	-9.65	-10.04	-10.25	-10.09	-9.87
4	-10.06				-10.24				-10.24			
5	-10.04				-9.68				-9.93			
6	-9.81				-8.93				-9.83			
DELTA	0.45	2.13	0.93	0.20	1.30	3.43	1.32	0.08	0.57	1.03	0.214	0.210
Rank	3	1	2	4	2	1	3	4	2	1	3	4

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A. Prediction for MRSN with optimal parameters

The high value for MRSN can be predicted from following equation using optimum levels of parameters. The MRSN values at optimal levels are taken from Table 7. Eq. 10, 11 & 12 describe the calculation for MRSN with zinc coated brass wire at optimal levels of significant factors.

Weightage MRR W=5, SR W=5

$$\alpha'_{MRSN} = T_{ON\,2} \quad (10)$$

$$\alpha'_{MRSN} = -8.95 \text{ db}$$

Weightage MRR W=7, SR W=3

$$\alpha_{MRR} = T_{ON\,3} + T_{OFF\,1} - \mu'_{MRSN} \quad (11)$$

$$\alpha_{MRSN} = -7.76 \text{ db}$$

Weightage MRR W=3, SR W=7

$$\alpha_{MRR} = T_{ON\,2} \quad (12)$$

$$\alpha_{MRSN} = -9.30 \text{ db}$$

Table 8 shows the data obtained by using Eq. (2) – Eq. (6) to find MRSN value for confirmatory experiments. Table 8 also shows the values for predicted values for MRSN and values obtained by experiments performed at optimum levels of parameters to achieve maximum MRR and less surface roughness.

Table 8 Calculation of MRSN value for confirmatory experiment and error obtained

Plain Brass wire													
MRR (W)	SR (W)	Experimental Values		L_{ij}		$N_{ij}=L_{ij}/L_i^*$		W_iN_{ij}		TL_j	MRSN (db)	Predicted MRSN (db)	Error %
		MRR	SR	MRR	SR	MRR	SR	MRR W=5	SR W=5				
W=5	W=5	6.97	2.41	0.021	5.808	0.493	0.730	2.465	3.651	6.117	-7.86	-8.54	8.65
W=7	W=3	8.60	2.62	0.014	6.670	0.324	0.850	1.619	4.250	5.869	-7.686	-7.4	3.72
W=3	W=7	4.90	1.99	0.042	3.960	0.998	0.498	4.988	2.490	7.478	-8.738	-9.40	7.5
Zinc Coated brass wire													
MRR (W)	SR (W)	Experimental Values		L_{ij}		$N_{ij}=L_{ij}/L_i^*$		W_iN_{ij}		TL_j	MRSN (db)	Predicted MRSN (db)	Error %
		MRR	SR	MRR	SR	MRR	SR	MRR	SR				
W=5	W=5	9.45	2.31	0.011	5.336	0.453	0.800	2.263	4.000	6.263	-7.968	-8.95	12.32
W=7	W=3	10.97	2.43	0.008	5.905	0.336	0.885	1.679	4.427	6.106	-7.857	-7.76	1.23
W=3	W=7	6.13	1.81	0.027	3.276	1.076	0.491	5.378	2.456	7.834	-8.940	-9.30	4.02

W=Weightage

L_i^* (MRR)=0.042, L_i^* (SR)=7.953 Plain Brass wire

L_i^* (MRR)=0.025, L_i^* (SR)=6.670 Zinc Coated brass wire

IV. CONCLUSIONS

In this research the multi-optimization is carried out using MRSN method. Prior to this, experiments are performed using L18 mixed OA using four process parameters viz., pulse on time, pulse off time, peak current and spark gap set voltage. The multi response optimization is executed for different weightage for MRR and SR. The weightage applied in the calculation is decided from literature survey and personal experience. It is found that the pulse on time and pulse off time are the main parameters whose values can change the output for material removal rate and surface finish. The optimal levels for significant factors are taken and for non significant factors the levels, higher S/N ratios levels are taken as optimum levels to perform confirmation experiments. The results obtained by confirming experiments show a significant improvement from the predicted values.

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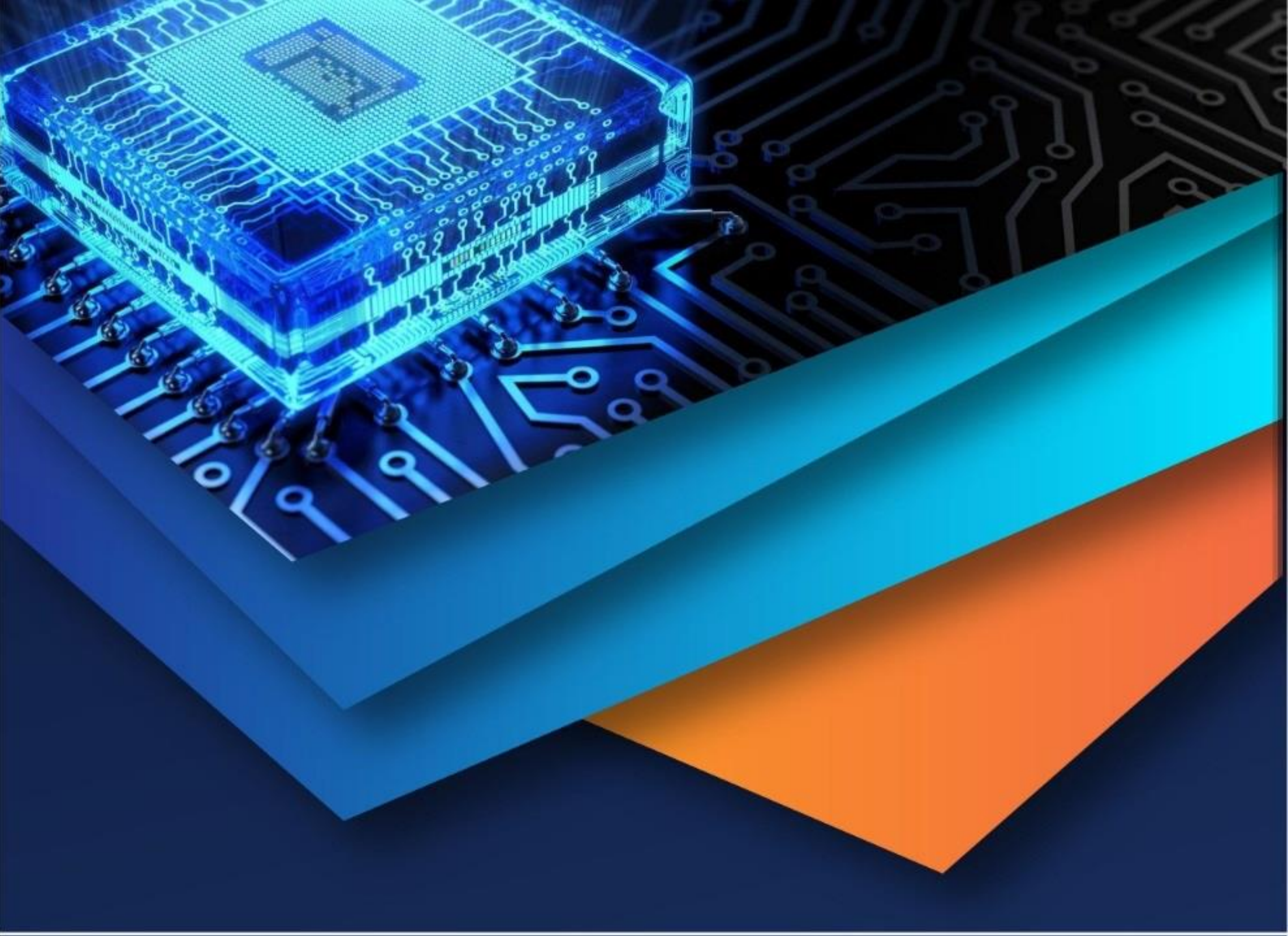

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