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Experimentation and Optimization of Surface Roughness in WEDM Process using Full Factorial Design integrated PCA Approach

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ABSTRACT

Application of WEDM is growing rapidly since the last three decades due its several advantages and applicability of the process to produce complicated intrinsic, extrinsic shapes of miniaturized size, so there is a need to analyze and optimize the process. In this research work the experiments were conducted using the general full factorial design methodology with 48 experimental runs. The values response parameters Ra, Rq and Rz were measured and the effect of process parameters wire type, wire tension, power, pulse on time and discharge current on these responses were studied qualitatively and quantitatively using main effect plots, interaction plots and ANOVA. Finally the optimal process parameter setting for responses were found by using full factorial design integrated PCA Approach.

***Keywords* -** Surface Roughness, ANOVA, Full factorial design, PCA, Multi Performance Index

I. INTRODUCTION

EDM (Electro Discharge Machining) is an electro thermal non- traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. Electric Discharge Wire Cutting Electric discharge wire cutting (EDWC), commonly called wire EDM, is a special form of electric discharge machining that uses a small diameter wire as the electrode The rapid development and evolution of technology since the last few decades are having a great impact on the development of WEDM, as many sophisticated, intrinsic, extrinsic shape of miniature sized component, irrespective of hardness can be machined with the help of WEDM. . Since the last three decades many investigations have been made for analyzing, modelling and optimizing the WEDM process. Ahmet Hasçalýk et. al [1] investigated the machining characteristics of AISI D5 tool steel in wire electrical discharge machining process. During experiments, parameters such as open circuit voltage, pulse duration, wire speed and dielectric fluid pressure were changed to explore their effect on the surface roughness and metallurgical structure. M.S. Hewidy et. al [2] studied the WEDM machining parameters of Inconel 601 material such as: peak current, duty factor, wire tension and water pressure on the metal removal rate, wear ratio and surface roughness. Kuriakose and Shunmugam [3] used multiple regression model to represent relationship between input and output variables and a multi-objective optimization method based on a Non-Dominated Sorting Genetic Algorithm (NSGA) was used to optimize Wire-EDM process. Kanlayasiri and Boonmung [4] used Analysis of variance (ANOVA) technique to find out the parameters affecting the surface roughness. Rajurkar and Wang [5] carried out investigation to determine the process performances such as machining rate and surface finish with overall parameters of a WEDM machine. Spedding and Wang [6] selected the pulse-width, the time between two pulses, the wire mechanical tension and the injection set-point as the factors (input parameters), whilst the cutting speed. Surface roughness and the surface waviness were the responses (output parameters). Many of the experiments carried out by previous researchers have been performed on trainee WEDM machines which are having limitations on process parameters. So to bridge the gap and to consider the process parameters like power and type of wire, machining process is needed to be conducted on a production WEDM model. Also the single level, multi-level interaction effects of these process parameters on different response parameters like Material Removal Rate (MRR), Surface Roughness (SR) and cutting rate etc. is needed to be investigated. In this investigation the impact of process parameters wire type, wire tension, Ton, Ip and power on Surface Roughness (Ra, Rq and Rz values) has been studied using AISI D2 tool steel as workpiece.

II. EXPERIMENTAL DETAILS

All the experiments were conducted on AC PROGRESS V2 (GF AgieCharmilles technology) WEDM machine. The enlarge view of experimental set-up with tool and workpiece have been shown in Figure1.

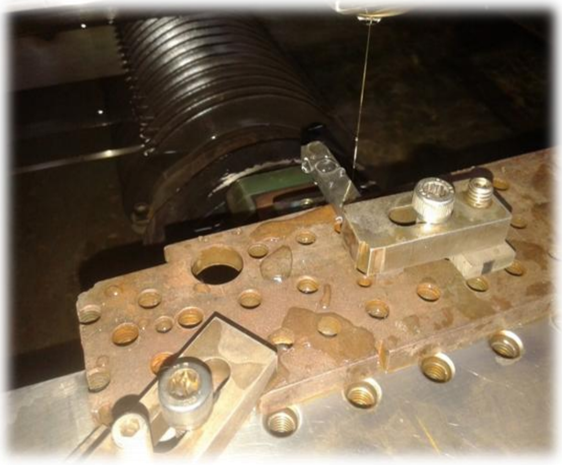

Figure .1: Enlarge viewed of experimental set-up with tool and workpiece

The measurement of Surface Roughness (Ra, Rq and Rz values) were made with portable MITUTOYO, SURFTEST SJ.210 and is shown in Figure2, with parameters cut-off length, Ln = 4 mm, sample length, Lc = 0.8mm and filter = 2CR ISO.

Figure.2: MITUTOYO, SURFTEST SJ.210 used for measurement of surface roughness

II. FULL FACTORIAL DESIGN

Here the influence of input parameters i.e., wire type, wire tension, power, pulse on time and discharge current on performance parameters Ra, Rq and Rz have been investigated with the help of full factorial method. For each run one number of replicate was created to consider the effect of variation in performance parameters, so a total of 48 runs were conducted in the investigation. The experiment was designed using general full factorial design considering the input parameters at different level as tabulated below in table 1.

Table 1: Factors and their levels

Process Parameters					
Parameter	Symbol	Level			units
		1	2	3	
Wire type	W_{type}	0.2Zn Coated Brass	0.2 non-coated brass	0.25 non-coated brass	NA
Wire tension	W_T	13	15	-	N
Power	P	30	40	-	J/min
Pulse On time	Ton	27	32	-	µs
Discharge current	Ip	12	14	-	A

The basic aim of implementing full factorial design methodology is to conduct the experiments in a designed manner so that the main effects, interaction effectscan be studied qualitatively as well as in a quantitative manner.

III. PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal component analysis (PCA) is a mathematical procedure that transforms a number of correlated variables into a number of uncorrelated variables called principal components.

In this investigation three principal components has been calculated and from these principals' components, MPI (Multi Performance Index) has been calculated. Based upon the MPI values the optimal process parameter setting for a machining process can be decided.

IV. EXPERIMENTAL RESULT:

The experimental result of 48 runs designed by full factorial design has been tabulated as below in table 2.

Table 2: Experimental results

Run Order	Wire Type	Wire Tension	Power	Ton	Ip	SR(Ra)	SR(Rq)	SR(Rz)
1	0.2 Coated	13	30	27	12	1.989	2.468	11.936
2	0.2 Coated	13	30	27	14	3.040	8.698	16.306
3	0.2 Coated	13	30	32	12	1.956	2.427	13.247
4	0.2 Coated	13	30	32	14	2.651	3.383	16.185
5	0.2 Coated	13	40	27	12	2.149	2.674	13.382
6	0.2 Coated	13	40	27	14	2.997	3.731	17.512
7	0.2 Coated	13	40	32	12	1.957	2.427	11.009
8	0.2 Coated	13	40	32	14	2.402	3.001	14.813
9	0.2 Coated	15	30	27	12	1.833	2.380	13.858
10	0.2 Coated	15	30	27	14	2.574	3.217	17.157
11	0.2 Coated	15	30	32	12	2.032	2.525	12.499
12	0.2 Coated	15	30	32	14	2.395	2.978	14.562
13	0.2 Coated	15	40	27	12	1.935	2.406	12.217
14	0.2 Coated	15	40	27	14	2.240	2.823	15.474
15	0.2 Coated	15	40	32	12	2.057	2.572	12.818
16	0.2 Coated	15	40	32	14	2.617	3.171	14.613
17	0.2 Non-coated	13	30	27	12	1.767	2.147	9.8730
18	0.2 Non-coated	13	30	27	14	2.049	2.502	11.998
19	0.2 Non-coated	13	30	32	12	2.170	2.658	12.241
20	0.2 Non-coated	13	30	32	14	2.200	2.732	13.372
21	0.2 Non-coated	13	40	27	12	1.978	2.433	11.830
22	0.2 Non-coated	13	40	27	14	2.097	2.635	12.954
23	0.2 Non-coated	13	40	32	12	1.974	2.430	11.182
24	0.2 Non-coated	13	40	32	14	2.355	2.963	15.576
25	0.2 Non-coated	15	30	27	12	1.801	2.243	11.554
26	0.2 Non-coated	15	30	27	14	2.105	2.696	13.924
27	0.2 Non-coated	15	30	32	12	2.042	2.510	12.540
28	0.2 Non-coated	15	30	32	14	2.279	2.834	14.141
29	0.2 Non-coated	15	40	27	12	1.993	2.522	13.569

Run Order	Wire Type	Wire Tension	Power	Ton	Ip	SR(Ra)	SR(Rq)	SR(Rz)
30	0.2 Non-coated	15	40	27	14	2.350	2.860	15.578
31	0.2 Non-coated	15	40	32	12	2.055	2.534	12.404
32	0.2 Non-coated	15	40	32	14	2.240	2.802	13.783
33	0.25 Non-coated	13	30	27	12	1.898	2.323	11.097
34	0.25 Non-coated	13	30	27	14	1.836	2.260	11.297
35	0.25 Non-coated	13	30	32	12	2.169	2.732	12.916
36	0.25 Non-coated	13	30	32	14	2.380	2.936	13.901
37	0.25 Non-coated	13	40	27	12	1.946	2.433	11.789
38	0.25 Non-coated	13	40	27	14	2.231	2.705	12.416
39	0.25 Non-coated	13	40	32	12	2.038	2.643	14.736
40	0.25 Non-coated	13	40	32	14	1.956	2.454	13.227
41	0.25 Non-coated	15	30	27	12	1.715	2.113	10.306
42	0.25 Non-coated	15	30	27	14	1.971	2.523	13.411
43	0.25 Non-coated	15	30	32	12	2.234	2.811	14.418
44	0.25 Non-coated	15	30	32	14	2.100	2.580	12.956
45	0.25 Non-coated	15	40	27	12	1.897	2.392	13.236
46	0.25 Non-coated	15	40	27	14	2.272	2.790	13.527
47	0.25 Non-coated	15	40	32	12	1.809	2.273	11.735
48	0.25 Non-coated	15	40	32	14	2.416	3.024	14.033

V. RESULTS AND DISCUSSIONS:

Principal Component Analysis (PCA) methodology is used for calculating principal components and MPI. The Eigen Vector, Eigen Values, cumulative variation and explained variation were calculated and has been tabulated in Table 3.

The three principal components have been calculated using the following formulae:

PC1 = (Normalized Ra x 0.570) + (Normalized Rq x 0. 597) + (Normalized Rz x 0. 564)

PC2 = (Normalized Ra x (-0.667)) + (Normalized Rq x (-0.063)) + (Normalized Rz x 0.742)

PC3 = (Normalized Ra x (-0.479)) + (Normalized Rq x 0.800) + (Normalized Rz x (-0.362))

The MPI has been found using the following formula

MPI=PC1 x 0.774 + PC2 x 0.137 +PC3 x 0.089

The result of principal components and MPI has been tabulated in Table 4.

The main effect plots and interaction effect plot of different process parameters on MPI has been shown in Figure 3 to Figure 8.

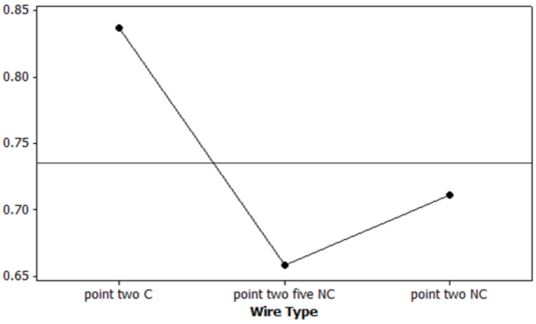

Figure 3: Data mean of MPI vs wire type

From Figure 3 it can be concluded that better surface finish can be achieved by using 0.25 non-coated brass wire. Figure 4 clearly indicates that increase in wire tension increases the surface finish. Figure 5, 6 and 7 shows that with the increase in power, Ton and Ip surface roughness increases.

Table 3: Explained variation and Eigen vector

Principal Component	Eigen value	Explained variation	Cumulative variation (%)	Eigen vector		
				Ra	Rq	Rz
PC1	2.3219	0.774	77.4	0.570	0.597	0.564
PC2	0.4111	0.137	91.1	-0.667	-0.063	0.742
PC3	0.2670	0.089	100.0	-0.479	0.800	-0.362

Table 4: Principal Components and MPI

S. No.	Normalized Value			Principal Components			MPI
	Ra	Rq	Rz	PC1	PC2	PC3	
1	0.21	0.51	0.51	0.72	0.21	0.12	0.59
2	0.84	0.93	0.85	1.51	0.02	0.03	1.17
3	0.29	0.55	0.59	0.82	0.21	0.09	0.67
4	0.73	0.94	0.93	1.50	0.14	0.07	1.19
5	0.34	0.65	0.55	0.89	0.14	0.16	0.72
6	1.00	0.88	0.90	1.60	-0.06	-0.10	1.23
7	0.19	0.52	0.21	0.54	0.00	0.25	0.44
8	0.64	0.95	0.65	1.30	0.00	0.22	1.03
9	0.09	0.35	0.54	0.56	0.32	0.04	0.48
10	0.50	0.81	0.81	1.23	0.21	0.12	0.99
11	0.25	0.50	0.46	0.70	0.14	0.11	0.57
12	0.53	0.82	0.62	1.14	0.06	0.18	0.91
13	0.17	0.75	0.49	0.82	0.20	0.34	0.69
14	0.76	0.96	0.96	1.55	0.15	0.06	1.22
15	0.27	0.61	0.17	0.61	-0.09	0.30	0.49
16	0.66	0.96	0.59	1.28	-0.06	0.24	1.01
17	0.04	0.15	0.47	0.38	0.31	-0.07	0.33
18	0.26	0.62	1.00	1.08	0.53	0.01	0.91
19	0.35	0.59	0.39	0.77	0.01	0.16	0.61
20	0.38	0.85	0.99	1.29	0.43	0.14	1.07
21	0.21	0.47	0.38	0.61	0.11	0.14	0.50
22	0.40	0.75	0.74	1.09	0.24	0.14	0.89
23	0.20	0.78	0.26	0.73	0.01	0.44	0.61
24	0.27	1.00	0.80	1.20	0.35	0.38	1.01
25	0.07	0.20	0.33	0.34	0.19	0.01	0.29
26	0.30	0.79	0.58	0.97	0.18	0.28	0.80
27	0.34	0.48	0.34	0.68	-0.01	0.10	0.53
28	0.39	0.71	0.53	0.94	0.09	0.20	0.76
29	0.22	0.55	0.37	0.66	0.09	0.20	0.54
30	0.50	0.83	0.58	1.11	0.05	0.21	0.88
31	0.27	0.78	0.44	0.86	0.10	0.33	0.71
32	0.41	0.91	0.67	1.15	0.17	0.29	0.94
33	0.14	0.25	0.23	0.36	0.06	0.05	0.29
34	0.25	0.37	0.00	0.37	-0.19	0.17	0.27
35	0.35	0.85	0.72	1.12	0.25	0.25	0.92
36	0.32	0.68	0.64	0.94	0.22	0.16	0.77
37	0.23	0.54	0.70	0.85	0.33	0.07	0.71
38	0.40	0.74	0.53	0.97	0.08	0.21	0.78
39	0.25	0.89	0.66	1.04	0.26	0.35	0.88
40	0.19	0.93	0.79	1.11	0.41	0.36	0.94

41	0.00	0.00	0.05	0.03	0.03	-0.02	0.02
42	0.20	0.42	0.14	0.44	-0.06	0.19	0.35
43	0.34	0.74	0.53	0.93	0.12	0.23	0.76
44	0.30	0.66	0.68	0.95	0.26	0.14	0.78
45	0.14	0.36	0.41	0.52	0.18	0.07	0.44
46	0.43	0.73	0.78	1.12	0.24	0.09	0.91
47	0.24	0.70	0.49	0.83	0.16	0.27	0.69
48	0.40	0.76	0.99	1.24	0.43	0.06	1.02

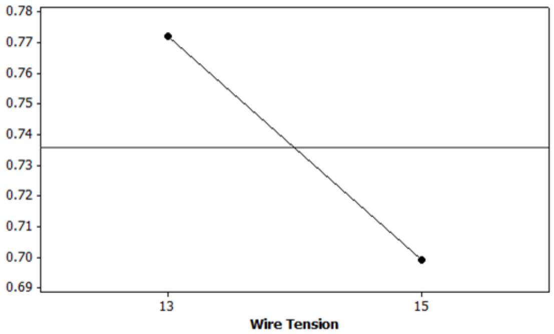

Figure 4: Data mean of MPI vs wire tension

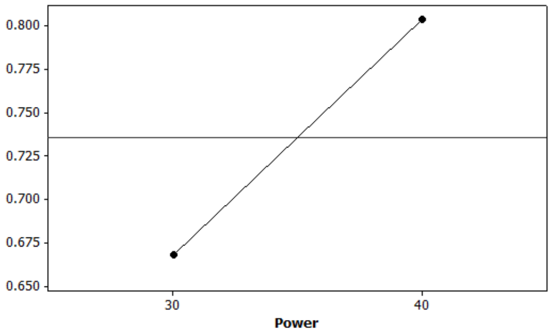

Figure 5: Data mean of MPI vs power

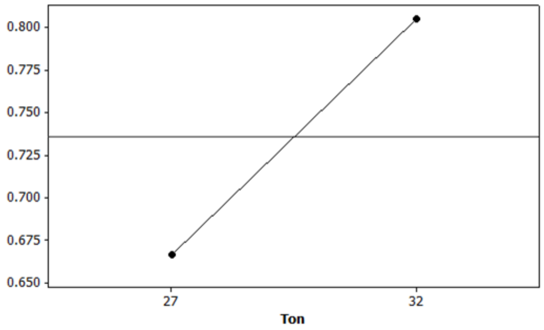

Figure 6: Data mean of MPI vs Ton

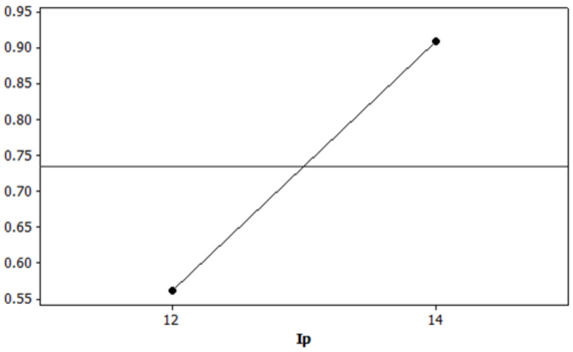

Figure 7: Data mean of MPI vs Ip

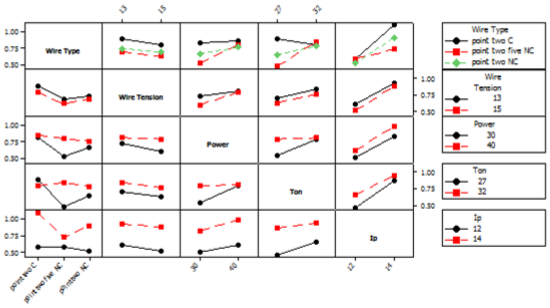

Figure 8: Interaction effect plots on MPI

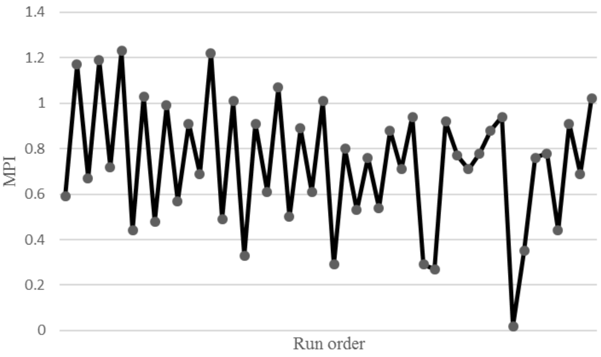

Figure 9: MPI vs run order

Table 4: Analysis of Variance for MPI

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%C
Wire Type	2	0.27166	0.27166	0.13583	469.67	0.000	7.5
Wire Tension	1	0.06380	0.06380	0.06380	220.61	0.000	1.8
Power	1	0.22005	0.22005	0.22005	760.89	0.000	6.1
Ton	1	0.22825	0.22825	0.22825	789.24	0.000	6.3
Ip	1	1.45255	1.45255	1.45255	5022.58	0.000	40.1
Wire Type*Wire Tension	2	0.00125	0.00125	0.00063	2.17	0.161	0.0
Wire Type*Power	2	0.12745	0.12745	0.06373	220.35	0.000	3.5
Wire Type*Ton	2	0.44415	0.44415	0.22208	767.89	0.000	12.3
Wire Type*Ip	2	0.29130	0.29130	0.14565	503.63	0.000	8.0
Wire Tension*Power	1	0.03797	0.03797	0.03797	131.29	0.000	1.0
Wire Tension*Ton	1	0.00075	0.00075	0.00075	2.60	0.135	0.0
Wire Tension*Ip	1	0.00285	0.00285	0.00285	9.86	0.009	0.1
Power*Ton	1	0.16217	0.16217	0.16217	560.74	0.000	4.5
Power*Ip	1	0.00585	0.00585	0.00585	20.24	0.001	0.2
Ton*Ip	1	0.03255	0.03255	0.03255	112.56	0.000	0.9
Wire Type*Wire Tension*Power	2	0.01226	0.01226	0.00613	21.20	0.000	0.3
Wire Type*Wire Tension*Ton	2	0.00318	0.00318	0.00159	5.50	0.022	0.1
Wire Type*Wire Tension*Ip	2	0.10818	0.10818	0.05409	187.03	0.000	3.0
Wire Type*Power*Ton	2	0.06436	0.06436	0.03218	111.28	0.000	1.8
Wire Type*Power*Ip	2	0.04283	0.04283	0.02141	74.05	0.000	1.2
Wire Type*Ton*Ip	2	0.00643	0.00643	0.00321	11.12	0.002	0.2
Wire Tension*Power*Ton	1	0.00317	0.00317	0.00317	10.96	0.007	0.1
Wire Tension*Power*Ip	1	0.00385	0.00385	0.00385	13.32	0.004	0.1
Wire Tension*Ton*Ip	1	0.01300	0.01300	0.01300	44.96	0.000	0.4
Power*Ton*Ip	1	0.01650	0.01650	0.01650	57.06	0.000	0.5
Error	11	0.00318	0.00318	0.00029			0.1
Total	47	3.61958					100
S = 0.0170060 R-Sq = 99.91% R-Sq(adj) = 99.62%							

Figure 8 represents the interaction plot of process parameters on MPI. Figure 9 shows the variation of MPI wrt run order. Table 4 shows the ANOVA of MPI. From table 4, it can be seen that, Ip is having the most significant impact with a majority contribution of 40.1% on MPI. Next to Ip the two level interaction effect (Wire Type*Ton) is having a contribution of 12.3%.Two level interaction parameters (Wire Tension*Ton) and (Wire Type*Wire Tension) were found to be insignificant toward MPI.

VI. CONCLUSION

From the MPI the optimal process parameter setting was found to be 0.2 coated wire type, wire tension =13N, power =40J/min, Ton 27µs, Ip =14A for obtaining the optimal surface finish. The most significant contribution towards surface finish was of Ip with a contribution percentage of 40.1. Analysis of the results developed from the current work promoters quite a few possible additions to the research. Simulation of SR can be done with ANSYS or similar software and simulated result and experimental result can be compared. This investigation was made for roughening operation, so similar attempt of investigation can be made for finishing and semi-finishing operation also. More level of process parameters can be consider to get more accurate and precise result with the help of response surface methodology and taguchi philosophy.

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