MULTI RESPONSE OPTIMIZATION OF EDM PARAMETERS FOR MONEL K-500

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Abstract
This paper presents optimization of the multi response parameter of electric discharge machine (EDM) for drilling operation of Monel K-500 material. Various control parameters (pulse current, gap voltage, pulse duration, pulse off time and dielectric pressure) is optimize using multi performance characteristic (material removal rate (MRR), electrode wear rate (EWR), over cut (OC), and taper angle (TA), while using 1 *mm* diameter tubular brass electrode. Using ANOVA analysis optimum values of metal removal rate (MRR), electrode ware rate (EWR), Over cut (OC) and taper angle is found to be gap voltage 60V, pulse current 12A, pulse duration 8µs, pulse off 2µs, and dielectric pressure 80kg/cm^2; gap voltage 50V, pulse current 8A, pulse duration 10µs, pulse off 6µs, and dielectric pressure 100kg/cm^2; gap voltage 50V, pulse current 10A, pulse duration 8µs, pulse off 4µs, and dielectric pressure 90kg/cm^2, and gap voltage 50V, pulse current 8A, pulse duration 8µs, pulse off 4µs, and dielectric pressure 90kg/cm^2 respectively for single response parameter.

Keywords: Multi-response parameters; Taguchi method; EDM; Monel K-500.

Symbols

ANOVA	Analysis of Variance
EDM	Electric Discharge Machining
EWR	Electrode Wear Rate
MRR	Material Removal Rate
OA	Orthogonal Array
OC	Over Cut
SNR	Signal to Noise Ratio
SR	Surface Roughness
TA	Taper Angle

Introduction

Electrical discharge machining, more commonly known as electrical discharge machining (EDM), is one of the non- conventional machining processes most widely used in industry. In the EDM process, there is no direct contact between the part and the electrode and repetitive electrical discharges are produced between them in a dielectric medium. The high temperatures reached (about 20,000 °C) melt and vaporize the material of the part, and no mechanical stresses take place. The machining performances of the process are evaluated in terms of material removal rate (MRR), electrode wear rate (EWR), and surface roughness (SR). Results confirm that the use of negative polarity leads to higher material removal rate (MRR), electrode wear (EW), and surface roughness (SR). Results confirm that the use of negative polarity leads to higher material removal rate whereas positive polarity is recommended when low values of EW and a good surface roughness are needed. Moreover, values of 22.2854 and 15.3602 mm^3/min are achieved for negative and positive polarity, respectively. [1]. An automated and intelligent system was developed by Yilmaz *et* *al.*[2], for EDM hole drilling operations on aerospace alloys, namely Inconel 718 (IN718) and Ti-6Al-4V (Ti64).The comparative study of copper and brass electrode reveals that copper electrode performs better than brass electrode to achieve the high material removal rate, less electrode rate and better surface quality of the hole in terms of taper ness for the same set of control parameters. Due to high electrical resistivity, low melting point and low thermal conductivity of brass electrode, its wears rapidly and decrease the shape accuracy of the machined parts. The improvement in SNR of GRG for copper and brass electrodes were found to be 0.9631 dB, 0.2459 dB respectively. ANOVA results of grey relational grade reveal that dielectric pressure is most significantly affect the EDM performance of AISI 329 stainless steel when brass electrode is used. Correspondingly, pulse off time is found to be most influencing parameter when copper electrode is used [3]. A detail review of the research trends , state of the art technology of high-performance machining of advanced materials using Die Sinking EDM, WEDM, Micro-EDM, Dry EDM AND RDE-EDM [4]. Dry electrical discharge machining (EDM) was proposed based on an analysis of the oxygen EDM mechanism, a dry EDM approach with an oxygen gas mixture was proposed, Second, dry EDM on cryogenically cooled work pieces [5]. A detail review of Micro-EDM process based on the thermoelectric energy between the work piece and newly developed method to produce micro-parts within the range of 50 µm -100 µm. describes the characteristics, parameters of material removal rate and the tool wear rate that are essential in the Micro-EDM process [6]. A reports on the EDM research relating to improving performance measures, optimizing the process variables, monitoring and control the sparking process, simplifying the electrode design and manufacture by Ho and Newman[7]. The development of a theoretical model to develop the tool path for generating a desired work piece surface profile. The application of the model is illustrated for micro and macro EDM by Wear Compensation machining flat slots. A review of tool wear compensation techniques was presented by Narasimhan et al. [8]. Optimization of multi response parameters of Inconel 600 on EDM using rotary brass hollow tubular electrode reported for optimized value of control parameters for high MRR, [9]. This paper reports multi response input parameter optimization using Taguchi method and ANOVA analysis. The optimization of response parameter of electric discharge machine (EDM) with multi quality characteristics is reported in this paper based on orthogonal array (OA) with Taguchi methodology. Signal to noise ratio (SNR) and ANOVA analysis were used to find out optimum level of the process parameters [10].

Experimental details

Experimental setup

The experimental work was carried out with the help of special purpose EDM Drill machine (EDD 44) made by Sparkonix (India) PVT. Ltd. Feed rate of consumable brass electrode was controlled and regulated with the help of automatic servomotor control mechanism of EDM drill machine. A special rotary head has been fabricated and attached to the quill of the EDM machine to provide rotary motion to the electrode. The electrode-rotating device consists of a precision spindle, a timer belt drive mechanism, and a speed control unit. The spindle was designed with built-in seals to effect flushing through the electrode. Actual photograph of EDM drill machine is shown in Fig.1

Fig.1: Photograph of special purpose EDM drill machine (EDD 44)

Material used

A sample work piece of100mm×100mm×10mm size named as Monel K-500 material were used for the multi response parametric optimization of EDM drill machine. Typical properties of Monel K-500 are tabulated in Table 1 were as its chemical composition is tabulated in Table 2.

Table1: Typical properties of Monel K-500

Properties	**Monel K-500**
Density	8.44g/cm^3
Melting point	1350^0C
Coefficient of expansion	13.7μm/m^0C(20-100^0C)
Modulus of rigidity	66KN/mm^2
Modulus of elasticity	179KN/mm^2

Table 2: Chemical composition of Monel K-500

Element	Ni	Cu	Fe	Al	Ti
Concentration (weight %)	63% min	30%	2% max	2.3%-3.15% max	0.35%-0.85% max

Experimental electrode specification

Single hole tubular brass electrode of 1 *mm* diameter and 400 *mm* length was used as a tool for performing drilling operation on the Monel K-500 material. The chemical composition of the electrode is tabulated in Table 3.

Table 3: Chemical composition of the brass electrode

Components	Cu	Zn	Pb	Fe
Weight (%)	60-63	35.5	2.5-2.75	Max0.5

Design of Experiment

No of experiment was design using Taguchi methodology; L18 Orthogonal array was selected for the experimentation on the basis of number of control factor and its level for degree of freedom 9.Optimum process parameter was selected with the help of Taguchi method as it has been established method in the field of manufacturing. ANOVA was used to find out effect of input processes parameter on the experimental results. L18 orthogonal array is tabulated in Table 4whereas control parameter of experimentation is tabulated in Table 5.

Table 4: L18 orthogonal array

S. No.	Gap Voltage	Pulse Current	Pulse Duration	Pulse off Time	Dielectric Pressure
1	50	8	6	2	80
2	50	8	8	4	90
3	50	8	10	6	100
4	50	10	6	2	90
5	50	10	8	4	100
6	50	10	10	6	80
7	50	12	6	4	80
8	50	12	8	6	90
9	50	12	10	2	100
10	60	8	6	6	100
11	60	8	8	2	80
12	60	8	10	4	90
13	60	10	6	4	100
14	60	10	8	6	80
15	60	10	10	2	90
16	60	12	6	6	90
17	60	12	8	2	100
18	60	12	10	4	80

Table 5: Control parameters and levels

Control Parameters	**Level 1**	**Level 2**	**Level 3**
Gap Voltage (V)	50	60	-
Pulse Current (A)	8	10	12
Pulse Duration (μs)	6	8	10
Pulse Off Time (μs)	2	4	6
Dielectric Pressure (kg/cm^2)	80	90	100

Calculation of response parameters

Tool wear rate of brass electrode and metal removal rate of a work piece (Monel K-500) was evaluated by measuring initial and final weight of electrode and work piece before and after experimentation in stipulated time duration using Sartorius weighing machine (BSA 22 025-CW) of least and max count 0.01*gm* and 2200 *gm* respectively. MRR, OC and TA of Monel K-500, EWR of brass electrode was evaluated with relation reported by Sharma *et al.* [9].

Evaluation of individual process performance

Signal to noise ratio (S/N) in Taguchi methodology will give the resistance to the variation from noise factor whereas identified higher value of control parameter will reduces the effect of noise factor during the machining operation. By knowing influencing control parameter of the experimentation, it becomes quite easy to have a quality product at low manufacturing cost in lesser time duration. Higher is better for MRR and lower is better for EWR, OC, TA. ANOVA has been carried out to examining the influence of individual control parameters on quality characteristics. The SNR was calculated using relation reported by Sharma et al. [9]. Experimental results of MRR, EWR, OC and TA shown in Table 6.

Table 6: Experimental results of MRR, EWR, OC, and TA

S.N.	MRR (mm^3/s)	EWR (mm^3/s)	OC (mm)	TA (radian)	η_{mrr}	η_{ewr}	η_{oc}	η_{ta}
1	0.0797	0.0566	0.1175	0.0234	-21.97	24.94	18.59	32.61
2	0.0803	0.0598	0.1375	0.0024	-21.90	24.46	17.23	52.39
3	0.0136	0.0108	0.0675	0.0114	-37.32	39.33	23.41	38.86
4	0.0599	0.0229	0.0125	0.0274	-24.45	32.80	38.06	31.24
5	0.0327	0.0216	0.0187	0.0124	-29.70	33.31	34.53	38.13
6	0.0400	0.0198	0.1250	0.0249	-27.95	34.06	18.06	32.07
7	0.0829	0.0706	0.1250	0.0249	-21.62	23.02	18.06	32.07
8	0.1209	0.0480	0.0375	0.0074	-18.35	26.37	28.51	42.61
9	0.1579	0.0673	0.1875	0.0124	-16.03	23.43	14.53	38.13
10	0.0339	0.0187	0.1125	0.0224	-29.39	34.56	18.97	32.99
11	0.1241	0.0897	0.0625	0.0124	-18.12	20.94	24.08	38.13
12	0.0592	0.0706	0.0625	0.0124	-24.55	23.02	24.08	38.13
13	0.1021	0.0609	0.0750	0.0149	-19.81	24.30	22.49	36.53
14	0.1777	0.0883	0.0500	0.0099	-15.00	21.58	26.02	40.08
15	0.1371	0.0867	0.1500	0.0299	-17.25	21.23	16.47	30.48
16	0.0473	0.0824	0.1625	0.0074	-26.50	21.68	15.78	42.61
17	0.0377	0.0204	0.100	0.0049	-28.47	33.80	20.00	46.19
18	0.1674	0.0768	0.0625	0.0122	-15.52	22.29	24.08	38.27

Evaluation of Multiple Response Parameters

Evaluation of SNR is required for the optimization of multiple responses parameters as follows:

Using Taguchi Methodology.

For higher the better performance characteristics, the loss function can get,

$$\text{Lij} = \frac{1}{n}\sum_{k=1}^{n}(1/Y_{ijk}^2) \quad (1)$$

For lower the better performance characteristics, the loss function can get,

$$\text{Lij} = \frac{1}{n}\sum_{k=1}^{n}(Y_{ijk}^2) \quad (2)$$

Normalized loss function can be evaluated as

$$S_{ij} = \frac{Lij}{Li} \quad (3)$$

Total loss function,

$$TL_j = \sum_{i=1}^{n}(W_i).(S_{ij}) \quad (4)$$

The multi-response SNR in the j^{th} experiment,

$$\eta_{mj}=-10\log(TL_j) \quad (5)$$

The different weightage order of response characteristics assumed as W1, W2, W3 and W4 will represents the MRR, EWR, OC and TA respectively. Case 1: Equal weightage to all response parameters (W1 = 25%, W2 = 25%, W3 = 25%, W4 = 25%). Case 2: For equal and higher MRR, EWR, equal and lower OC and TA (W1 = 30%, W2 = 30%, W3 = 20%, W4 = 20%).Case 3: For equal and higher OC and TA, intermediate MRR and lower EWR (W1 = 20%, W2 = 10%, W3 = 35%, W4 = 35%)

The maximized value of multi-response SNR was used to solve the simultaneous optimization problem. Multi-response SNR is equivalent to SNR (Ƞ) for optimization of single response characteristics. The optimal control factor setting found in this way was verified by the confirmation experiment.

Confirmation of Experiment

Experimental results are verified with the confirmation experiment for the improvement of the performance characteristics using the optimal level of the process parameters. Results of confirmation experiment are shown in Table 7, 8 and 9 for Case 1, 2 and 3 respectively.

Table 7: Result of confirmation experiment for Case-1

Improvement in multi-response SNR = 0.7198 dB

Experimental Error = 6.1545%

Response parameter	Initial process parameter	Optimum response parameters (Experiment)
Level	V1, I2, Pon3, Poff1, Pd2	V2, I3, Pon3, Poff1, Pd1
MRR(mm^3/s)	0.1371	0.0575
EWR(mm^3/s)	0.0867	0.0654
OC(mm)	0.15	0.100
TA(radian)	0.0299	0.0021
Multi-response SNR	6.4784	5.7586

Table 8: Result of confirmation experiment for Case-2

Improvement in multi-response SNR = 1.3527 dB

Experimental Error = 8.5448%

Response parameter	Initial process parameter	Optimum response parameters (Experiment)
Level	V1, I3, Pon1, Poff2, Pd1	V2, I3, Pon3, Poff3, Pd1
MRR(mm^3/s)	0.0829	0.1287
EWR(mm^3/s)	0.0706	0.0768
OC(mm)	0.125	0.200
TA(radian)	0.0249	0.0074
Multi-response SNR	7.6032	6.2505

Table 9: Result of confirmation experiment for Case-3

Response parameter	Initial process parameter	Optimum response parameters (Experiment)
Level	V1, I1, Pon1, Poff1, Pd1	V2, I3, Pon1, Poff1, Pd1
MRR(mm^3/s)	0.0797	0.0987
EWR(mm^3/s)	0.0566	0.0981
OC(mm)	0.1175	0.1625
TA(radian)	0.0234	0.0168
Multi-response SNR	9.6576	8.1840

Improvement in multi-response SNR = 1.4736 dB

Experimental Error = 8.7286%

Result and discussion

For Single Response parameter

Mean effects plot for SN ratios: larger is better for a metal removal rate (MRR) represented in Fig.3 which shows that the SN ratio will increases by 11.24% as gap voltage increases from 50V to 60V for level-1 and level-2 respectively.

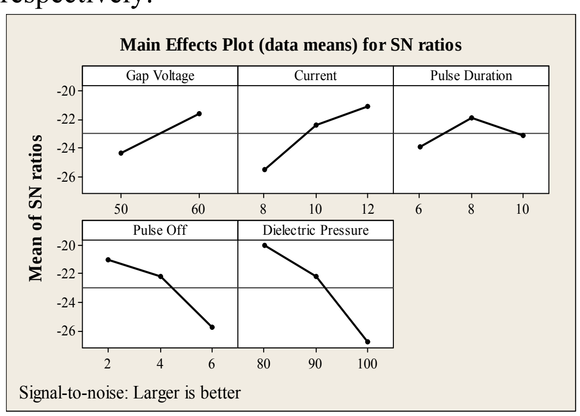

Fig. 3: SNR plot for MRR

SN ratio also increases by 12.44% and 5.72% when current increases from 8A to 10A and 10A to 12 A respectively in case of level 1, 2 and 3 whereas in case of pulse duration initially it increases by 8.47% and then decreases by 5.31% from level-1 to 2 and level 2 to 3 respectively. SN ratio will decreases in case of pulse off and dielectric pressure by 5.41%, 10.62%, for level 2 and 16.00%, 20.83% for level -3 respectively.

Mean of SNR (smaller is better) for EWR is shown in Fig.4. SNR will decreases by 14.82% as gap voltage increases from 50V to 60V form level-1 to level-2.

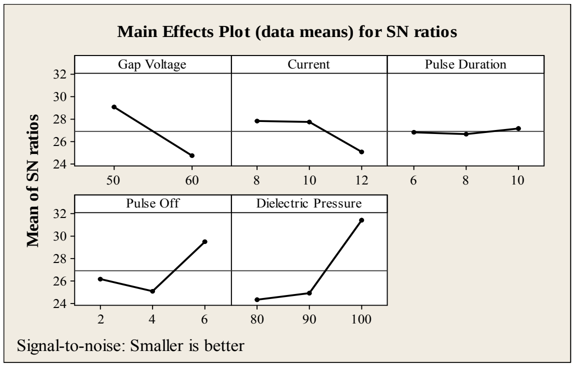

Fig. 4: SNR plot for EWR

SN ratio also decreases by 0.28% and 9.71% when current increases from 8A to 10A and 10A to 12 A respectively in case of level 1, 2 and 3 whereas in case of pulse duration initially it decreases by 0.85% and dramatically increases by 2.13% from level-1 to 2 and level 2 to 3 respectively. SN ratio will decreases in case of pulse off by4.31% from level-1 to level-2 and then increases by 17.75% from level-2 to level-3 while dielectric pressure increases by 2.21%, 26.77%, from level-1 to 2 and level-2 to 3 respectively. Mean of SNR (Smaller is better) plot for OC is shown in Fig.5 which shows that the SN ratio will decreases by 11.51% as gap voltage increases from 50V to 60V form level-1 to 2.

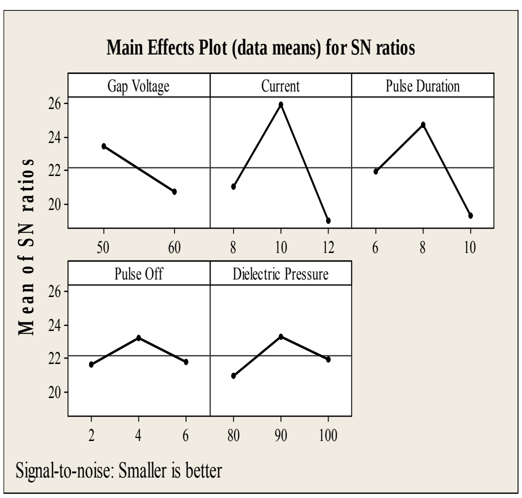

Fig. 5: SNR plot for OC

SN ratio also increases by 23.17% from level-1 to level-2 and then decreases by 26.79% when current increases from 8A to 10A and 10A to 12A. Whereas in case of pulse duration initially it increases by 12.45% and then decreases by 21.90% from level-1 to 2 and level 2 to 3 respectively. SN ratio will first increase then decreases in case of pulse off and dielectric pressure by 7.57%, 11.39%, for level 2 and 6.35%, 5.77% for level -3 respectively.

SNR plot for TA is shown in Fig.6, which shows that the SN ratio will decreases by 1.51% as gap voltage increases from 50V to 60V form level-1 tolevel-2 .

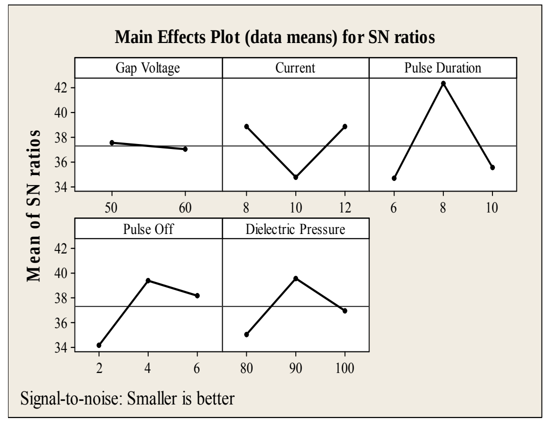

Fig.6: SNR plot for TA

SNR also decreases by 10.55% from level-1 to level-2 and increases by11.79% from level-2 to level-3, when current increases from 8A to 10A and 10A to 12 A. Whereas in case of pulse duration initially it increases by 21.88% and then decreases by 15.92% from level-1 to 2 and level 2 to 3 respectively. SN ratio will first increase then decreases in case of pulse off and dielectric pressure by 15.62%, 13.08%, for level 2 and 3.14%, 6.69% for level -3 respectively.

For multiple response parameters

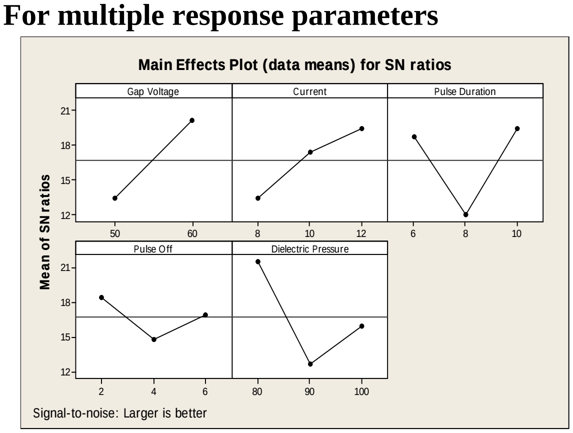

Fig.7: Multi-response SNR plot

SNR plot for case-1 is shown in Fig.7, which shows that the SN ratio will increases by 50.18% as gap voltage increases from 50V to 60V form level-1 tolevel-2. SNR also increases by 29.84% from level-1 to level-2 and further increases by 11.57% from level-2 to level-3, when current increases from 8A to 10A and 10A to 12 A. Whereas in case of pulse duration initially it decreases by 35.93% and then increases by 62.10% from level-1 to 2 and level 2 to 3 respectively. SN ratio will first decrease then increases in case of pulse off and dielectric pressure by 20.11%, 14.93%, for level 2 and 41.28%, 26.36% for level -3 respectively.

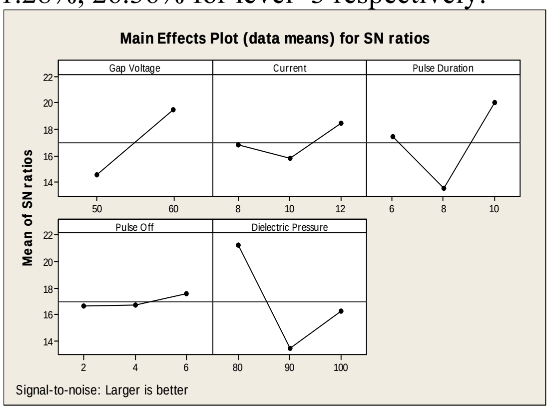

Fig.8: Multi-response SNR plot

SNR plot for case-2is shown in Fig.8, which shows that the SN ratio will increases by 34.02% as gap voltage increases from 50V to 60V form level-1 tolevel-2. SNR decreases by 6.25% from level-1 to level-2 and increases by16.88% from level-2 to level-3, when current decreases from 8A to 10A and increases from 10A to 12 A. Whereas in case of pulse duration initially it decreases by 23.31% and then increases by 47.67% from level-1 to 2and level 2 to 3 respectively. SN ratio increases from level-1 to level-2 and level-2 to level-3 as pulse off 0.66% and 4.89% respectively. Then decreases in case of dielectric pressure by 36.18% from level-1 to level-2 and increases by 21.05% from level-2 to level-3.

Fig.9: Multi-response SNR plot

SNR plot for case-3 is shown in Fig.9, which shows that the SN ratio will increases by 41.02% as gap voltage increases from 50V to 60V form level-1 tolevel-2. SNR increases by 25.66% from level-1 to level-2 and increases by10.18% from level-2 to level-3, when current increases from 8A to 10A and 10A to 12 A. Whereas in case of pulse duration initially it decreases by 27.30% and then increases by 36.98% from level-1 to 2 and level 2 to 3 respectively. SN ratio will first decrease then increase in case of pulse off and dielectric pressure by 14.26%, 1.27%, for level 2 and 31.89%, 6.95% for level -3 respectively.

Experimental results

Optimum values of control parameters are evaluated as below with ANOVA.

- Optimum value of MRR: gap voltage 60V, pulse current 12A, pulse duration 8μs, pulse off 2μs, and dielectric pressure 80kg/cm².
- Optimum value of EWR: gap voltage 50V, pulse current 8A, pulse duration 10μs, pulse off 6μs, and dielectric pressure 100kg/cm².
- Optimum value of OC: gap voltage 50V, pulse current 10A, pulse duration 8μs, pulse off 4μs, and dielectric pressure 90kg/cm².
- Optimum value of TA: gap voltage 50V, pulse current 8A, pulse duration 8μs, pulse off 4μs, and dielectric pressure 90kg/cm².
- Optimum value of control parameters for multi-performance optimization were found to be for case-1:gap voltage 50V, pulse current 8A, pulse duration 10μs , pulse off 6μs , and dielectric pressure 100kg/cm².
- Optimum value of control parameters for multi-performance optimization were found to be for case-2: gap voltage 50V, pulse current 8A, pulse duration 10μs , pulse off 6μs , and dielectric pressure 100kg/cm².
- Optimum value of control parameters for multi-performance optimization were found to be for case-3: gap voltage 50V, pulse current 8A, pulse duration 10μs , pulse off 6μs , and dielectric pressure 100kg/cm².

Conclusions

The experimental result confirms the multi performance optimization of response parameters using Taguchi method. From the results of the confirmation experiment, three different cases of the multi response parameters are made as per the industrial requirement and confirmation experiments was carried out for the validation of results.

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