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An Investigation and Machining Parameter Optimization on Inconel 713 by Using DOE Technique

Manikandan M [a], Jeeva R [b]

[a] *Graduateship / Associate Membership, Mechanical Engineering, Indian Institute of Industry Interaction Education and Research*
[b] *Professor / Project Coordinator / Indian Institute of Industry Interaction Education and Research*
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A B S T R A C T

Thermal energy is generated in a plasma channel and dispersed through the work piece, tool, and dielectric in the Electrical Discharge Machining (EDM) mechanism of metal removal. The procedure is primarily employed when complex shapes, intricate pieces, or extremely hard materials need to be machined. In order to control the most connected parameters of the EDM process, such as material removal rate (MRR) and surface integrity characteristics like average surface roughness (Ra) and hardness (HR), the objective of this work is to investigate the influence of three design factors: current (I), pulse (V), pulse on (Ton), and pulse off (Toff). Additionally, these factors will be quantified. The L9 orthogonal array was followed in the execution of the studies. Different parameters, including ampere rating, pulse on time, and pulse off time, were used for each experiment. The best combination of pulse on time of 5µs, pulse off time of 8µs, amps-16, machining time, and MRR was found for INCONEL 713 Surface Roughness. Amps were 14 and the pulse on time was 5µs. The pulse off time was 9µs. In particular, the output response was primarily dependent on the pulse timing.

1. Introduction

1.1 Electric Discharge Machining

One non-traditional thermo-electric machining method is called electric discharge machining. Localized material melting and vaporization removes material from the work item. When two electrodes are held close to one another in a dielectric medium and a strong potential difference is applied across them, electric sparks are produced between them. Because of the sparks that erupt between the two electrode surfaces, there are isolated hot spots. The work piece material vaporizes and melts in this limited zone. The dielectric flow removes the majority of the vaporized and melted material from the inter-electrode gap as debris particles. Electric power is provided in the form of brief pulses to avoid overheating. Wherever there is the tiniest space between the tool and the work piece surface, spark arises. This gap widens and the subsequent spark moves to a new spot on the work piece surface as material is removed by a spark. This causes many sparks to appear at different points throughout the work piece's surface that correspond to the work piece-tool gap. Over time, a uniform gap distance forms throughout the gap between the tool and the work piece as a result of the material loss caused by sparks. Thus, a replica of the tool surface shape is formed on the work piece as shown in Figure 1.1

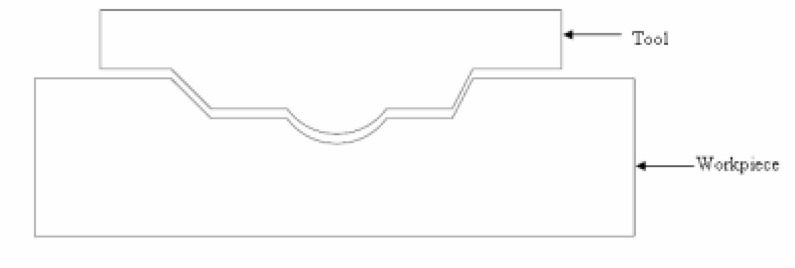

Figure 1: Tool shape and corresponding cavity formed on work piece After EDM Operation

2. EDM Process

2.1 Theories of Material Removal

In electrical discharge machining, the erosion action of electric sparks between two electrodes is the basis for material removal. A number of theories have been proposed in an effort to explain the intricate "erosive spark" phenomenon. The following are the theories,

1. Electro-mechanical theory
2. Thermo-mechanical theory
3. Thermo-electric theory

2.2. Electro-Mechanical Theory

This idea implies that the concentrated electric field causes material particles to be abrased. According to the hypothesis, when the electric field in the work piece surpasses the cohesive forces in the material lattice, the material particles split. Any thermal effects are disregarded in this hypothesis. There is not enough experimental evidence to support this theory.

2.3. Thermo-Mechanical Theory

According to this notion, "flame jets" are responsible for the melting of material during EDM operations, which results in material removal. These so-called flame jets are created by the discharge's different electrical effects. Nevertheless, this idea is inconsistent with experimental findings and falls short of providing a cogent account of the impact of spark erosion.

2.4. Thermo-Electric Theory

This idea, which is best supported by experimental data, contends that the high discharge current intensity causes an exceptionally high temperature, which in turn leads to metal removal during EDM operations. Despite having strong evidence, this theory's interpretation issues prevent it from being regarded as definitive and comprehensive.

3. General Experimental Setup

3.1. Experimental Setup

The electrodes were machined to a 25 mm length and 20 mm diameter cylindrical shape. A 32 mm diameter and 15 mm thick HDS cylindrical item needs to be planned.

Figure 2: General Experimental Setup

3.2. Electrode Materials

3.2.1 Graphite Electrode

The most widely used substance for electrodes is graphite. In the EDM sector, graphite was first used over fifty years ago. The first well-known manufacturer to introduce graphite into the EDM market was General Electric. It was referred to by the trade name "Gentrode." Graphite, in contrast to other metal-based electrode materials, has certain special qualities that set it apart from the competition and make it an excellent choice for an EDM electrode. Compared to other materials, it has a heat resistivity that is thousands of degrees higher. It transforms directly from a solid state into a gas rather than melting like other materials do. This has the additional drawback of causing a dusty cloud to build in the workplace rather than breaking and remaining under the dielectric. If precautions are not taken, this could be dangerous. It's a good idea to vacuum up dust to keep yourself from breathing graphite dust while at work.

Even though graphite is the greatest material to use as an electrode, there are certain chemical restrictions. Because it is porous, it can introduce undesirable contaminants when submerged in dielectric fluid. When cutting, trapped moisture might produce steam, which ruins the electrode. Due to this problem, it is better to use denser graphite which shows little penetration even after long hours of soaking. One other way of using graphite without facing problem is to heat the electrode in oven for an hour at 121°C.

4. WORK MATERIAL DETAILS

Work material –Inconel 713 steel

Work material size–25 x 25 x6 mm thickness

4.1 Chemical Properties

Table 1 Chemical composition

s.no	ELEMENT	COMPOSITION IN WEIGHT %I MIN	MAX
1	Carbon, C	0.08-	0.2
2	Chromium	12.0	14
3	Iron	6.00	10.00
4	Silicon	--	0.50
5	Manganese	--	1.00
6	Sulfur	--	0.015
7	Copper	--	0.50
8	Nickel		72.0 min
9	Molybdenum	3.8	5.2

Application

Air frame. Air craft engine, Marine chemical parts, Heat exchanger Condenser, and evaporator tubing are generally made of INCONEL 713.

4.2 Machining Parameters (General)

Table 2: Experimental details

Voltage (V)	V80±5%
Discharge Current (A)	8, to 20
Servo Control	Electro Mechanical
Polarity	Normal (Electrode – Positive)
Dielectric fluid	Commercial Grade Kerosene
Flushing side	Flushing with Pressure
Work piece Material	INCONEL 713
Electrode Material	Graphite

4.3 Design of Experiment

Table 3: Process parameters and their levels

S.No	Pulse on time	Pulse off time	Gap current
1	5	7	12
2	6	8	14
3	7	9	16

Table 4: An Orthogonal Array L_9 Formation

Trial No.	Pulse on time µs	Pulse off time µs	Gap current amps
1	5	7	12
2	5	8	14
3	5	9	16
4	6	7	14
5	6	8	16
6	6	9	12
7	7	7	16
8	7	8	12
9	7	9	14

4.4 Experimental Data

Table 5: Input & Out Responses

TRIAL NO.	Pulse on time µs	Pulse off time µs	Current Amps	RA Micron	MT min	MRR gm/min
1	5	7	12	1.612	28	0.027
2	5	8	14	1.893	23	0.045
3	5	9	16	2.469	18	0.043
4	6	7	14	2.212	19	0.042
5	6	8	16	2.186	15	0.058
6	6	9	12	2.420	20	0.045
7	7	7	16	2.168	13	0.067
8	7	8	12	2.898	16	0.055
9	7	9	14	3.142	18	0.051

4.5 Surface Roughness's (Analysis of Result)

Table 6 S/N Ratio values for the experiments-Ra

TRIAL NO.	T ON µs	T OFF µs	CURRENT Amps	RA Micron	S/N Response valve (db) for Ra
1	5	7	12	1.612	-4.14730
2	5	8	14	1.893	-5.54301

3	5	9	16	2.469	-7.85042
4	6	7	14	2.212	-6.89570
5	6	8	16	2.186	-6.79300
6	6	9	12	2.420	-7.67631
7	7	7	16	2.168	-6.72119
8	7	8	12	2.898	-9.24197
9	7	9	14	3.142	-9.94412

Table 7: Response Table for Signal to Noise Ratios-Ra

Smaller is better

LEVEL	T ON	T OFF	AMPS
1	-5.847	-5.921	-7.022
2	-7.122	-7.193	-7.461
3	-8.636	-8.490	-7.122
DELTA	2.789	2.569	0.439
RANK	1	2	3

Table 8 Analysis of Variance-Ra

SOURCE	DF	SEQ SS	ADJ SS	F	P	% of contribution
T ON	2	0.84835	0.42418	4.18	0.193	47
T OFF	2	0.69318	0.34659	3.15	0.226	40
AMPS	2	0.03241	0.01621	0.16	0.862	2
ERROR	2	0.20273	0.10137			11
TOTAL	8	1.77669				100

4.6 Machining time (analysis of result

Table 9 S/N Ratio values for the experiments-MT

TRIAL NO.	**DESIGNATION**	T ON µs	T OFF µs	Current AMPS	MT min	**S/N Response valve (db) for mc**
1	$A_1B_1C_1$	5	7	12	28	-28.9432
2	$A_1B_2C_2$	5	8	14	23	-27.2346
3	$A_1B_3C_3$	5	9	16	18	-25.1055
4	$A_2B_1C_2$	6	7	14	19	-25.5751
5	$A_2B_2C_3$	6	8	16	15	-23.5218
6	$A_2B_3C_1$	6	9	12	20	-26.0206
7	$A_3B_1C_3$	7	7	16	13	-22.2789
8	$A_3B_2C_1$	7	8	12	16	-24.0824
9	$A_3B_3C_2$	7	9	14	18	-25.1055

Table 10 Response Table for Signal to Noise Ratios-MT

Smaller is better

LEVEL	T ON	T OFF	AMPS
1	-27.09	-25.60	-26.35
2	-25.04	-24.95	-25.97
3	-23.82	-25.41	-23.64
DELTA	3.27	0.65	2.71
RANK	1	3	2

Table 11: Analysis of Variance (ANOVA) results for the Roughness -MT

SOURCE	DF	SEQ SS	ADJ SS	F	P	% of contribution
T ON	2	84.222	42.111	7.73	0.114	52
T OFF	2	6.222	3.111	0.57	0.636	3
AMPS	2	59.556	29.778	5.47	0.155	38
ERROR	2	10.889	5.444			7
TOTAL	8	160.889				100

4.7 MRR (Analysis of Result)

Table 12 S/N Ratio values for the experiments-MRR

Trial No.	T ON μs	T OFF μs	Current Amps	MRR gm/min	SNRA1
1	5	7	12	0.027	-31.3727
2	5	8	14	0.045	-26.9357
3	5	9	16	0.043	-27.3306
4	6	7	14	0.042	-27.5350
5	6	8	16	0.058	-24.7314
6	6	9	12	0.045	-26.9357
7	7	7	16	0.067	-23.4785
8	7	8	12	0.055	-25.1927
9	7	9	14	0.051	-25.8486

Table 13 Response Table for Signal to Noise Ratios-MRR

Larger is better

Level	T ON	T/OFF	AMPS
1	-28.55	-27.46	-27.83
2	-26.40	-25.62	-26.77

3	-24.84	-26.70	-25.18
Delta	3.71	1.84	2.65
Rank	1	3	2

Table 14: Analysis of Variance (ANOVA) results for the Roughness -MRR

Source	DF	Seq SS	Adj MS	F	P	% OF CONTRIBUTION
T ON	2	0.000561	0.000280	6.77	0.129	54
T/OFF	2	0.000095	0.000047	1.14	0.466	9
AMPS	2	0.000300	0.000150	3.62	0.216	28
Error	2	0.000083	0.000041			9
Total	8	0.001039				100

5 Conclusion and Result

In this study, the Taguchi technique and ANOVA were used to obtain optimal machining parameters in the electrical discharge machining conditions. The experimental results were evaluated using Taguchi technique. The following conclusion can be drawn.

5.1 Optimal Control Factor

1. Surface Roughness-A1 (Pulse on time -5µs) B2 (Pulse off time -8 µs) C3(Amps-16)
2. Machining Timing- A1(Pulse on time -5µs)B3(Pulse off time -9 µs)C2(Amps-14)
3. Material Removal Rate- A1(Pulse on time -5µs)B3(Pulse off time -9 µs)C2(Amps-14)

5.2 Percentage Contribution of Process Parameter

1. Surface Roughness- Pulse on time 47%
2. Machining Timing -Pulse on time 52%
3. Material Removal – Pulse on time 54%

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