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Optimization of Process Parameters in WEDM Process

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ABSTRACT

Wire-cut Electric Discharge Machining is used to cut conductive metals of any hardness or that are difficult or impossible to cut with traditional methods. The objective of the present work is to investigate the effects of the various WEDM process parameters on the machining quality and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. The working ranges and levels of the WEDM process parameters are found using one factor at a time approach. The Taguchi technique has been used to investigate the effects of the WEDM process parameters and subsequently to predict set of optimal parameters for optimum quality characteristics in high chromium tool steels. This research outlines the Taguchi's parameter design approach, which has been applied to optimize machining parameters during machining process. This procedure eliminates the need for repeated experiments and saves time. The machining parameters investigated are Peak current, T-on, T-off and Wire feed rate. A series of experiments are conducted using WEDM. An orthogonal array (L9) has been used to conduct the experiments. The raw data and S/N analysis are employed to find the influence of selected parameters on MRR. Objective of the present work is to reveal the influence of four different process parameters Peak current, Pulse on time (T-ON), Pulse off time (TOFF) and Wire feed rate on Material Removal Rate (MRR) of SS 304 material for cutting on WEDM.

Keywords: *Taguchi Method; WEDM; Material Removing Rate.*

1.0 Introduction

In this growing world of technology, design and manufacturing we need more accurate and defect free deliverables like product, service, design and technology. With the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance is increasing. Wire-cut Electric Discharge Machining is used to cut conductive metals of any hardness or that are difficult or impossible to cut with traditional methods. This machine also specializes in cutting complex contours or fragile geometries that would be difficult to be produced using conventional cutting methods. Machine tool industry has made exponential growth in its manufacturing capabilities in last decade but still machine tools are not utilized at their full potential. This limitation is a result of the failure to run the machine tools at their optimum operating conditions. The problem of arriving at the optimum levels of the operating parameters has attracted the attention of the researchers and practicing engineers for a very long time. The objectives of the present of the various WEDM process parameters on the machining quality and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. The working ranges and levels of the WEDM process parameters are found using one factor at a time approach. work is to investigate the effects.

The Taguchi technique has been used to investigate the effects of the WEDM process

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parameters and subsequently to predict set of optimal parameters for optimum quality characteristics in high chromium tool steels. This research outlines the Taguchi's parameter design approach, which has been applied to optimize machining parameters during machining process. This procedure eliminates the need for repeated experiments and saves time. The machining parameters investigated are T-on, T-off, Peak Current and Wire Feed. A series of experiments are conducted using WEDM. An orthogonal array (L9) has been used to conduct the experiments. The raw data and S/N analysis are employed to find the influence of selected parameters on MRR. WEDM is a special form of the traditional EDM process in which the electrode is a continuously moving conducting wire. Material is eroded from the work piece by a series of discrete sparks between the work piece and the wire electrode (tool) separated by a thin film of dielectric fluid (de-ionized water) which is continuously force fed to the machining zone to flush away the eroded particles. The movement of the wire is controlled numerically to achieve the desired three - dimensional shape and accuracy for the work piece. Although the average cutting speed, relative machining costs, accuracy and surface finish have been improved many times since the commercial inception of the machine, much more improvement is still required to meet the increasing demand of precision and accuracy by different industries. It is a well-known fact that a high material removal rate and a very good surface finish can never be achieved simultaneously in WEDM process.

2.0 Literature Review

Huang et al. [1] applied Taguchi and Grey relational analyses to determine the optimal selection of machining parameters for the Wire Electrical Discharge Machining. They concluded that feed rate and Ton were the most influential factors on MRR, and Ton has a significant influence surface roughness. Mahapatra et al. [2] identified the significant machining parameters affecting the performance measures are as discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow using Taguchi's parameter design and also established nonlinear regression equations between process parameters and performance measures. Saurav Datta [3] developed quadratic mathematical models to represent the process behavior of wire electrical discharge machining (WEDM) operation. Hewidy et al. [4] established mathematical models correlating the various WEDM machining parameters (peak current, duty factor, wire tension and water pressure) with the metal removal rate, wear ratio and surface roughness using response surface methodology. Singh et al. [5] investigated the effect of various process parameters of WEDM like pulse on time (Ton), pulse off time (T off), gap voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT) to reveal their impact on the material removal rate of hot die steel (H- 11) using one variable at a time approach. Durairaja et al. [6] used Grey relational theory and Taguchi optimization technique to optimize the cutting parameters in Wire EDM for SS304. They reported that pulse on time has a major influence on the surface roughness (μm) and kerf width (mm) in both the Taguchi optimization method and Grey relational analysis. Martowibowo et al. [7] conducted experiments to optimize the input parameters of Wire EDM machine, such as no load voltage, capacitor, on-time, off-time, and servo voltage, for machining medium carbon steel ASSAB 760. The results revealed that the MRR and the SR are greatly influenced by the on-time and the taper angle, respectively.

This present work describes the optimization of WEDM process parameters using Taguchi technique and also to determine the influence of process parameters on the responses using ANOVA analysis. In the present work, statistical analysis software MINITAB 15 was used for the design of experiments and to perform ANOVA analysis.

3.0 Experimental Set-Up and Process Parameter Selection

3.1 Work piece material

The SS-304 steel plate of 100mm x 50mm x5mm size has been used as a work piece material for experiments in the present work. SS-304 is special high carbon high chromium tool-steel with good hardness and toughness properties. It is used for extreme load conditions such as hot-work forging, extrusion, bending, forming, deep-drawing, rim rolling, spinning and flow-forming, Coining dies, Cold extrusion dies, punches, tube end section forming rolls, plain rolls, dies for molding of ceramics, bricks, tiles, grinding wheels, tablets, abrasive plastics, thread-rolling dies, cold-heading tools, crushing hammers, swaging tools, gauges, measuring tools, guide rails, bushes, sleeves, knurling tools, sandblast nozzles, etc. SS-304 steel is a high carbon, high chromium tool steel alloyed with molybdenum and vanadium characterized by High wear resistance, high compressive strength, good through-hardening properties and high stability in hardening and good resistance to tempering-back. The working life and dimensional accuracy of D2 tool steel dies and tools can be improved with suitable heat treatment.

SS-304 steel is a high-carbon, high chromium tool steel alloyed with molybdenum and vanadium characterized by:

- High wear resistance
- High compressive strength
- Good through-hardening properties
- High stability in hardening
- Good resistance to tempering-back.

SS-304 has high wear resistance, combined with moderate toughness (shock-resistance). SS-304 can be supplied in various finishes, including the hot-rolled, pre-machined and fine machined condition. The chemical composition of this material as obtained by EDAX (Electro Dispersive X-ray Spectroscopy) test is given in table I.

Table I: Chemical Composition of SS304 Steel.

Material	C	Cr	Mn	Ni	Si	N	S	P	Fe
SS 304	0.08	18-20	2.00	8-12	0.75	0.10	0.030	0.045	Balance

3.2 Preparation of work piece specimen

The D2 tool steel plate of 100mm x 50mm x5mm size is mounted on the ELECTRONICASPRINTCUT WEDM machine tool and specimens of 5mm x 5mm x 13mm size are cut. The close up view of plate blank used for cutting the specimens is shown mounted on the EDM machine. A set of cut on the specimen is shown in figure below:

Fig 1: Test Sample

4.0 Experimentation

The experiments have been conducted on the SPRINTCUT WEDM from Electronica India PvtLtd. A diffused brass wire of 0.25 mm diameter is used as the cutting tool. D2 tool steel is a highcarbon high chromium alloy is used as the specimen. The specimen is of rectangular shapehaving a thickness of 5 mm. The deionized water is used as dielectric and its temperature is kept at 20ºC. The three input process parameters namely peak current (IP), pulse-on time (TON), pulse-off time (TOFF), wire feed (WF). Following steps have been carried out in cutting operation.

- The wire is made to cut vertically with the help of verticality block.
- The work piece is mounted and clamped on the work table with the help of bolts.
- A reference point on the work piece is set for setting work co-ordinate system (WCS).

The programming has been done with the reference to the WCS. The reference point has been defined by the ground edges of the work piece. The program is made for cutting operation of the work piece and a profile of 5 mm x 5 mm square has been cut.

Selection of Variables: The variables selected are T-on, T-off, IP and WF.

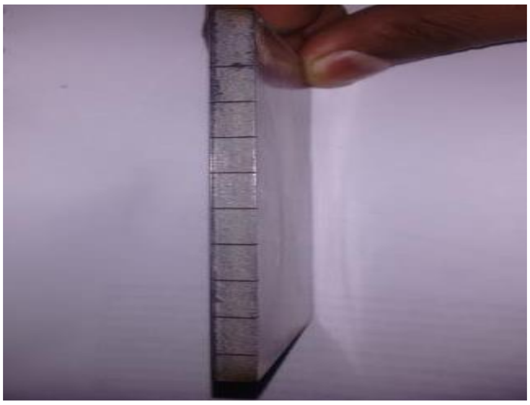
Selection of Levels: The levels selected are 3 for each of the variable.

Selection of Orthogonal Array: As three variables are considered in the present work and each having three levels, and the degree of freedom associated with one variable is 2 (Number of levels-1). So the degree of freedom associated with the three variables is 6. Hence, an orthogonal array having at least 6 DF is to be selected. In the present work, the L9 OA is selected.

Table 2: Parameters at Different Level

S No.	Parameters	Symbol	level 1	level 2	level 3	units
1	Pulse on time	ton	120	124	128	µ sec
2	Pulse off time	toff	55	58	62	µ sec
3	Peak current	ip	210	220	230	ampere
4	Wire feed rate	wf	4.5	5.5	6	mm/min

Fig.3 Test Sample after CNC Operation



5.0 Taguchi Method

Taguchi technique is a powerful statistical technique used for analyzing and optimizing the process parameters.

The Taguchi analysis uses orthogonal arrays from design of experiments theory to study the influence of a large number of variables on responses with a small number of experiments. In this method, the experimental results are transformed into a signal-to-Noise (S/N) ratio.

It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values.

Taguchi classified the quality characteristics into three categories such as Lower the better, Higher the better and Normal the better. The formula used for calculating S/N ratio.

Fig 2 CNC Machine

6.0 Experimental Results and Analysis

6.1. S/N ratio analysis

The S/N values are calculated with the help of software Minitab 16. The MRR value measured from the experiments and their corresponding S/N ratio values are listed in the given table:

Table 3 S/N Values

S. No.	S/N ratio
1	-55.0897
2	-52.5786
3	-53.3917
4	-52.7278
5	-52.0412
6	-51.2767
7	-50.4576
8	-50.4576
9	-49.5511

In this figure signal-to-noise ratio approach to measure the quality characteristic deviates from the desired value. S/N ratio is used as an objective function for optimizing parameters. Control factors are easily adjustable, and it is set by the manufacturer. These factors are most important in determining the quality characteristics.

6.2 Analysis of variance for S/N ratio

ANOVA results for MRR are given in table below. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. It can be observed from table V that the Peak Current, T-On, T-Off and WF affects the MRR by 13.48 %, 19.97% and 64.50%. The P value for the T-ON is less than 0.05 therefore significance of this parameter is under 95% confidence interval

Fig 3: Main Effect Plot for S/N Ratio

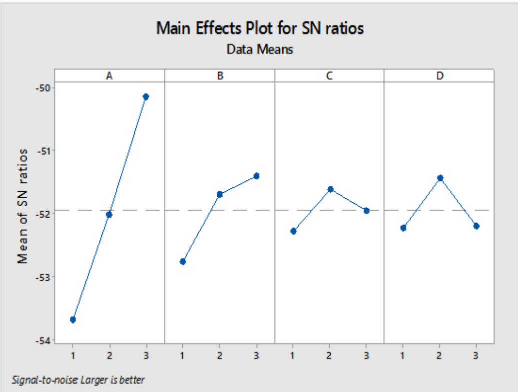


Fig 4: Main Effect Plot for Means

Table 4: Different Source and Respective Values

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.00582	0.00895	12.23	0.016
TON	1	0.00702	0.00052	43.24	0.003
TOFF	1	0.00397	0.00564	5.57	0.078
IP	1	0.00438	0.00276	0.10	0.765
WF	1	0.00571	0.00368	0.00	0.976
Error	4	0.00641	0.00198		
Total	8	0.0856			

The response table V shows the average of each response characteristics (S/N data) for each level of each factor. The table includes ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistics is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on.

6.3 Effect on material removal rate

Regardless of the category of the performance characteristics, greater S/N value corresponds to a better performance. Therefore the optimum level of process parameters is the level with the greatest value of S/N ratio.

Fig 5: Residual Plot for MRR

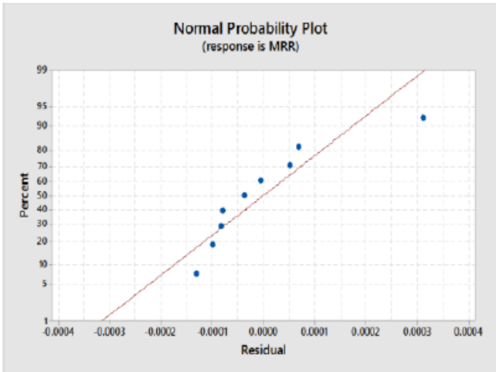


Figure 3 shows that the MRR increases with the increase in pulse on time and decreases with the increase in the pulse off time and spark gap set voltage. This is because the discharge energy increases with the pulse on time and peak current leading to a faster cutting rate. As the pulse off time decreases, the number of discharges within the given period becomes more which leads to a higher cutting rate. With increases in spark gap set voltage the voltage discharge gap gets widened resulting into a lower cutting rate and then sudden starts increasing. It is also evident that cutting arte is minimum at first level of pulse on time and maximum at first level of pulse off time.

6.4 Optimization

After analyzing S/N graphs and mean plots for optimal conditions for the selected response variable (Material Removal Rate), it is found that the MRR increases with the increase in pulse on time, and decreases with increase in pulse off time and spark gap set voltage. This is because the discharge energy increases with the pulse on time and peak current leading to a faster cutting rate. As the pulse off time decreases, the number of discharges within a given period becomes more which leads to a higher cutting rate. With increase in spark gap set voltage the average discharge gap gets widened resulting into a lower cutting rate and then sudden starts increasing. It is also evident that cutting rate is minimum at first level of pulse on time and maximum at first level of pulse off time.

Regression Equation:

MRR = -0.01694 + 0.000128 TON + 0.000052 TOFF + 0.000002 IP - 0.000003 WF

The optimal condition for the selected response variable (Material Removal Rate) are

Pulse-on time TON : 128 microseconds

Pulse-off time TOFF: 58 microseconds

Peak current IP : 220 Ampere

Wire feed rate WF : 5.5 mm3/sec

7.0 Conclusions

This confirmation test for the optimal parameter setting with its selected level was concluded to evaluate the quality characteristics for WEDM of SS304. Experiment 9 shows the highest signal to noise ratio values, indicating the optimal process parameter set of Ton, Toff, IP; WF has the best values among the nine experiments which can be compared with result of ANOVA for validation of result. The response value obtained from the confirmation experiment are MRR=0.00333 gm/sec

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