OPTIMIZATION OF WIRE ELECTRICAL DISCHARGE MACHINING PROCESS PARAMETERS USING TAGUCHI METHOD

Gijoy S[1], Abhilash S S[2], Hari Krishnan S J[3]
[1,2]Department of Mechanical Engineering, Sree Chitra Thirunal College of Engineering, Trivandrum, Kerala, India
[3]UG Student, Department of Mechanical Engineering, SCT College of Engineering, Trivandrum, Kerala, India

Abstract
Wire Electrical Discharge machining is a non-conventional machining process used in the machining material of complicated and irregular shapes with high dimensional accuracy which are not possible with the other conventional methods. The stainless steel 304 is considered in the present work. The experimentation has been completed using Taguchi's L9 orthogonal array with different input process parameters. The goal of given research work is to optimize the parameter of WEDM process by considering the input parameter of pulse on time, pulse of time, wire feed, wire tension and experiment have been conducted with the help of these input parameters in three levels and corresponding response on Material Removing Rate (MRR) and Surface Roughness(Ra). The setting of process parameters is determined by Taguchi's design of experiments. Signal to Noise(S/N) and analysis of variance (ANOVA) were used to analyze the effect of selected process parameters on MRR and Ra and identify the optimum cutting parameters setting.
Index Terms*:* Taguch's Method, WEDM, SS304, Signal to Noise Ratio, L9 Orthogonal Array, ANOVA

I. INTRODUCTION

The experimental setup and the experiment is designed and carried out at the KELTRAC which is placed at Aroor. The primary goal of the dissertation work is to predict the MRR, surface roughness, and kerf width the work is carried out in wire cut electro discharge machine of SS304 material by varying machining parameters .The wire cut electric discharge machine is comprised of a machine tool, a power supply unit and dielectric supply unit. The most operations handle by the automatic control system as programmed by the operator.

II EXPERIMENT WORK AND MEASUREMENT

A. Machine

The machine used for experiments is electronic Wire cut EDM, Model- ELPULS-40 A DLX, incorporated with molybdenum wire technology which is installed at KELTRAC, Aroor, Ernakulum, Kerala as shown in Fig. 6. The machine consists of a coordinate worktable, wire running system, wire frame, Micro computer based control cabinet and dielectric supply system. In this machine brass wire is used to perform cutting operation and wire is wound and stored a wire drum which can rotate at a speed of 1500 rpm. Guide pulleys are mounted on wireframe and wire can run through these guide pulleys at a speed of 11 m/sec in reversible directions alternatively. Work piece is mounted on the worktable with the help of clamps and bolts and the micro controller delivers the pulse signals to the servo motors which rotates accordingly and through the variable gears, lead screws and nuts, these motions will be transmitted to the worktable for performing the cutting operation.

B. Control Cabinet

Programming, controlling, pulse power supply and electric part of machine are integrated in one single unit i.e. Micro computer based control cabinet as shown in Fig. 4.3. This system uses industrial controlling computer as mainframe, equipped with controlling units like specialized circuit board for programming& controlling system and intelligent cutting.

C. Work Table

In older WEDM machines, servo systems were used to move the work table but now linear motors have replaced servo systems in majority of the machines. Linear motors are superior to rotating motors in travelling speed and positional accuracy. These motors can move with accuracy in increments of 1 micrometer. The linear motors and/or servo systems are the muscles of the work table enabling it to move along the programmed path. The CNC system controls the motions of the work table and follows the inputs given to it through a program. The motion controllers works in partnership with the CNC system and the linear motors. They control the high-speed and high-precision motions of linear motors based on commands from the CNC units. The motion controllers tell the work table where it is in comparison to the electrode. The entire system works on the principal of the Cartesian coordinate system. Every point within the work table of the machine can be defined and located thus enabling it to follow a given path allowing it to cut the programmed part. These CNC systems make WEDM machines highly reliable and productive.

D. Wire Electrode

EDM wire is the tool of the Wire EDM and it never makes contact with the material being machined. The work piece and the wire represents positive and negative terminals respectively in a DC electrical circuit and are always separated by a controlled gap. This gap is being filled with deionized water which acts as an insulator and cooling agent and also flushes away the eroded particles from the work material. The wire is continually being fed vertically through the work piece while the work piece is moved along a horizontal plane. The resultant motion along this horizontal plane cuts a slot through the work piece that is slightly larger than the diameter of the wire. Wire is typically perpendicular to the surface of the work piece, except when tapers are being machined, in which case the wire can pass through the material at an angle of up to 30 degrees. Wire selection basically depends on the properties of work piece material however an ideal wire electrode should possess following characteristics, i.e. High electrical conductivity, sufficient mechanical strength (tensile strength, elongation etc.) and optimum spark and flushing characteristics.

E. Types of wires

Copper: The first material used in the production of EDM wire was copper. Copper possesses excellent conductivity rating, low tensile strength, high melting point and low vapour pressure rating which severely limited its potential. As the power supplies and controllers for the wire-EDM became more sophisticated, they exceeded the capabilities of the pure copper wire. [24]

Brass: As new materials and demands came, developers subsequently experimented with the use of brass in order to meet the new demands. Brass is an alloy of copper and zinc. Generally, the higher the zinc percentage, the better the wire is for EDM. However, if the zinc concentration is too great, the wire may become difficult to fabricate consistently. The optimum balance between copper and zinc is an alloy in the range of 35–37% zinc and 63– 65% copper. Brass quickly became the most widely used electrode material for general purpose wire EDM. It is now commercially available in a wide range of tensile strengths and hardness.

Coated Wires: These wires are also called as plated or "stratified" wire or speed wires as they offer higher Metal removal rate. Brass wires cannot efficiently be produced with higher percentages of zinc than those that have been listed above, therefore a brass or copper wire core is coated with zinc in order to obtain the desired properties that are provided by zinc while maintaining sufficient levels of tensile strength and conductivity along with enhanced the properties of spark formation and flushing.

Fine Wires (Molybdenum & Tungsten) These wires are being used for high precision work on wire EDM machines, requiring small inside radii and thus wire diameters in the range of 0.001 - 0.030. Since brass and coated wires are not practical, due to their low load carrying capacity in these sizes, molybdenum and tungsten wires are used. These wires possess low conductivity, high melting points and low vapour pressure ratings, therefore these are not suitable for very thick work and have low metal removing rates if used. [25]

F. Selection of work piece

In this experiment AISI 304 stainless steel of size 150*15*10 mm3 plate is chosen for conducting the experiment. Grade 304 is the commonly used stainless steel; it is the utmost versatile applications and greatest use of stainless steel, offered in an extensive variety of good products, practices and qualities than any other. It has wonderful welding and forming characteristics. Grade 304 is freely brake or spool molded into a variability of work uses in the manufacturing, construction as well as automobile fields. The austenitic configuration provides these grades brilliant toughness, straight down to lower hotness. It has excellent oxidization prevention in a numerous range of full of atmosphere environments as well as lots of corrosive medium. It has good corrosion resistance in intermittent service and brilliant weld ability property in entirely available standard fusion methods, both with and without filler methods shown in fig. 3.2. Therefore it is applicable to make kitchen appliances, sinks, benches, architectural paneling, railings, heat exchangers, threaded fasteners, spring, chemical containers including for transport etc.

TABLE I: STRUCTURE VARIETIES FOR AISI 304 MARK STAINLESS STEEL

Grade		C	Si	P	S	Mn	Cr	Ni	N
304	Minimum	-	-	-	-	-	18	8	-
	Maximum	0.08	0.75	0.045	0.03	2	20	10.5	0.1

TABLE II: MECHANICAL PROPERTIES of AISI 304 GRADE STAINLESS STEEL

Grade	Tensile strength (Mpa)	Yield Strength 0.2% proof (Mpa) min	Elongation % (in 50 mm) min.	Rockwell (B) Max.	Brinell (HB) Max.
304	515	205	40	92	201

Fig. 1 AISI 304 stainless steel work piece before machining

III TAGUCHI DESIGN

Dr. Genichi Taguchi's approach or DOE is highly effective wherever and whenever it is suspected that the performance of a part or process is controlled by more than one factor. The main purpose is to give a clear understanding to make the DOE technique more effective in applications, and how relate the outcome of the technique to improve the quality of products and processes. When used for product design optimization, analytical simulation is the common approach, because hardware is not often available.

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings "of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Taguchi Method treats optimization problems in two categories,

1) Static Problems:

Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "Static Problem”. This is best explained using a P-Diagram which is shown below ("P" stands for Process or Product). Noise is shown to be present in the process but should have no effect on the output! This is the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process. The process is then said to have become robust.

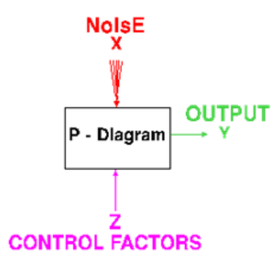

Fig. 2 P-Diagram for Static Problems

2) Dynamic Problems:

If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the "input signal / output" ratio is closest to the desired relationship. Such a problem is called as a "Dynamic Problem". This is best explained by a P-Diagram which is shown below. Again, the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process- is achieved by getting improved linearity in the input/output relationship.

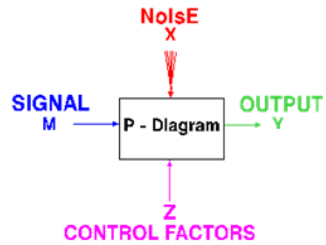

Fig. 3 P-Diagram for Dynamic Problems

A. Static Problem (Batch Process Optimization)

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

1) Smaller-the-Better:

n = -10 Log10 [mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all undesirable characteristics like “defects “etc. for which the ideal value is zero. Also, when an ideal value is finite and its maximum or minimum value is defined then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes,

n = -10 Log10 [mean of sum of squares of {measured - ideal}]

2) Larger-the-Better:

n = -10 Log10 [mean of sum squares of reciprocal of measured data]

This case has been converted to Smaller-the-Better by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the-better case.

3) Nominal-The-Best:

$$n = 10 \text{ Log10 } \frac{\text{Square of means}}{\text{variance}}$$

This case arises when a specified value is MOST desired, meaning that neither a smaller nor a larger value is desirable.

B. 8-Steps in Taguchi Methodology

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results.

The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, computer-aided-design, banking and service sectors etc. Taguchi method is useful for 'tuning' a given process for 'best' results.

Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process,

Step 1: Identify the main function, side effects and failure mode.

Step 2: Identify the noise factors, testing conditions and quality characteristics.

Step3:

Identify the objective function to be optimized

Step4:

Identify the control factors and their levels

Step5:

Select the Orthogonal Array Matrix Experiment

Step6: Conduct the Matrix Experiment

Step 7: Analyze the data; predict the optimum levels and performance.

Step 8: Perform the Verification Experiment and plan the future action

C. Taguchi Design Experiments in MINITAB 17

MINITAB 17 offers many possible ways in which an experiment can be carried out. A number of ordinary orthogonal arrays have been created to ease of experimental design. For each of these arrays can be used to design experiments to suit numerous experimental situations. A number of orthogonal arrays, such as L4, L8, L9, L12, L16, L18, and L27 and so on, created for two or three level factors. MINITAB 17 estimates response tables and creates main effects and S/N ratios plans intended for: S/N ratios [Signal-to-noise ratios] vs. control factors and Means vs. control factors.

A Taguchi design or an orthogonal array method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In this study, a three factor mixed level setup is chosen with an overall nine numbers of trials to be conducted and hence the OA L9 be there selected. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L9 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler.

The levels of experiment parameters and discharge pulse on time, pulse off time, wire feed, wire tension are shown in Table III and the design matrix is represented in Table IV.

TABLE III: PROCESS PARAMETERS, SYMBOLS AND THEIR RANGES

Process Parameters	Symbols	Units	Range Machine units
Pulse on Time	TON	μ s	105-125
Pulse off Time	TOFF	μ s	40-55
Wire Feed	EF	m/min	5-12
Wire Tension	WT	Gram	4-12

TABLE IV: ORTHOGONAL ARRAY (L9)

S. No.	Ton (μs)	Toff (μs)	WF (m/min)	WT (gms)
1	108	52	5	7
2	108	56	8	8
3	108	60	11	9
4	114	52	8	9
5	114	56	11	7
6	114	60	5	8
7	120	52	11	8
8	120	56	5	9
9	120	60	8	7

D. Measurement of Surface Roughness

Surface Roughness is the size of the surface texture. It is expressed in μm and denoted by Ra. If the value comes higher that means the surface is rough and if lower comes that means that the surface is smooth. The surface roughness values are measured by means of an apparatus portable type profilometer. After measurement calculate by arithmetic mean of three data is in use as the absolute value.

MRR is calculated as the proportion of the change of weight of the work piece before and after machining to the product of machining period and density of the material.

$$MRR = W/T \text{ (gm/sec)}$$

Where, W is the Weight of Material Removed after Machining and T is the Time in which material is removed

$$W = I - (R + w)$$

I = Initial weight of metal Specimen.

R = Remaining weight of metal specimen after Machining

w = Weight of piece which is cut from the specimen

IV RESULTS AND DISCUSSION

The present work was accomplished on an Electronica WEDM machine. The wire was made vertical with the help of vertical block. A reference point on work piece was set for setting work co-ordinate system. The reference point was defined by the ground edges of work piece.

TABLE V: FIXED PARAMETER

Work Material Stainless	Steel 304
Cutting Tool copper wire electrode	0.25mm
Servo Feed	2100 units
Flushing Pressure	1 units
Peak Voltage	20 volt
Height of work piece	10 mm

A. Influence of Process Parameters on MRR

Leading statistical analysis software MINITAB 17 was used for the design and analysis of experiments to perform the Taguchi and ANOVA analysis and to establish regression models. The optimization of process parameters using Taguchi method provides the evaluation of the effect of individual independent parameters on the identified quality characteristics. The statistical analysis of variance (ANOVA) was carried out. Based on the ANOVA, the contribution of each parameter in influencing the variation in quality characteristic was evaluated. The ANOVA also provides an indication of which process parameters are statistically significant. The results table for MRR and SR is shown in Table along with the input factors.

TABLE VI: RESPONSE TABLE

Sl.No	Ton	Toff	Wfeed	Wtension	MRR	SR
1	108	52	5	7	2.55	2.46
2	108	56	8	8	3.75	2.34
3	108	60	11	9	4.16	2.44
4	114	52	8	9	3.12	3.34
5	114	56	11	7	2.96	2.80
6	114	60	5	8	2.45	3.00
7	120	52	11	8	3.31	3.32
8	120	56	5	9	3.04	3.28
9	120	60	8	7	2.74	2.74

In this investigation, the S/N ratio was chosen according to the criterion, the “larger-the-better” in order to maximize MRR.

TABLE VII: S/N RATIO FOR MRR.

Level	Ton	Toff	Wfeed	Wtension
1	10.664	9.470	8.532	8.771
2	9.031	10.188	10.040	9.887
3	9.603	9.640	10.735	10.641
Delta	1.634	0.718	2.211	1.870
Rank	3	4	1	2

In the present study, MRR of WEDM was analyzed to determine the effect of WEDM process parameters on MRR and SR. The experimental results were transformed into a signal-to-noise (S/N) ratio using the Minitab statistical software. Main effects at all the levels of the chosen parameters are calculated and listed in Table VIII. The main effect for mean and S/N ratio is plotted. It is observed that the MRR is highest at the level 1 of Ton, at the level 3 of Toff and at the level 3 of the WT and level 3 of Wtension.

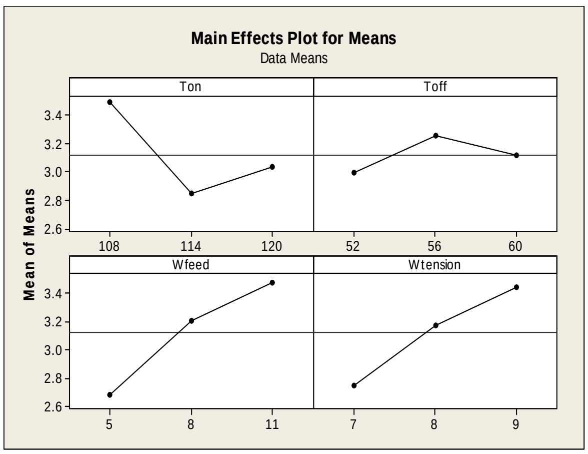

Fig 4.Main effects plots for mean of MRR.

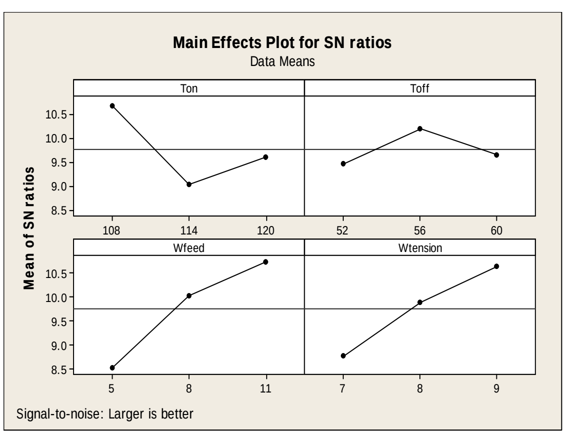

Fig 5.Main effects plots for S/N ratio of MRR.

TABLE VIII: ANALYSIS OF VARIANCE FOR S/N RATIO FOR MRR

Source	DF	Seq SS	Percentage of contribution
Ton	2	4.1230	22.971
Toff	2	0.8444	4.704
Wfeed	2	7.6687	42.726
Wtension	2	5.3124	29.59
Total	8	17.9485	1

The analysis of variances of the factors is shown in Table 6 which clearly shows that the Toff is not an important factor that influences MRR and Wfeed (42.726%) is the most influencing factor for MRR followed b y Wtension (29.59%).

B. Influence of Process Parameters on Surface Roughness

In this investigation, the S/N ratio was chosen according to the criterion, the "smaller-the-better" in order to minimize surface roughness.

TABLE IX: S/N RATIO FOR SR

Level	Ton	Toff	Wfeed	Wtension
1	-7.650	-9.572	-9.226	-8.506
2	-9.654	-8.882	-8.871	-9.117
3	-9.832	-8.682	-9.038	-9.513
Delta	2.181	0.890	0.355	1.008
Rank	1	3	4	2

In the present study, surface roughness of WEDM was analyzed to determine the effect of WEDM process parameters. Main effects at all the levels of the chosen parameters are calculated and listed in Table 7. The main effect for mean and S/N ratio is plotted . It observed that the Ra is lowest at the level 1(108)of Ton, at the level 3(60)of Toff and at the level 1(7) of the WT,at the level 2(8) 0f Wfeed. It is clear that the highest S/N ratio is the optimal level of each process parameter.

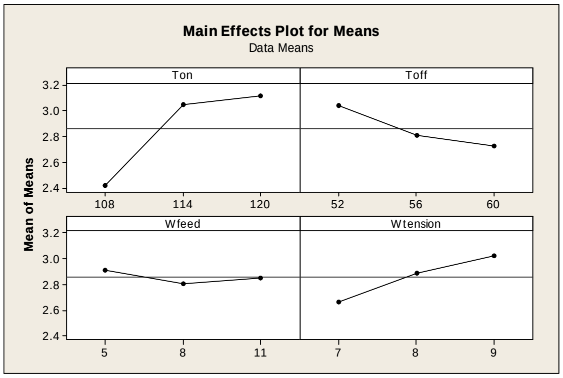

Fig 6. Main effects plots for mean of Ra.

The analysis of variances of the factors is shown in Table 8 which clearly indicates that Ton (74.302%) is the major factor affecting Ra of followed by Wtension (13.010) and Toff (11.052%).

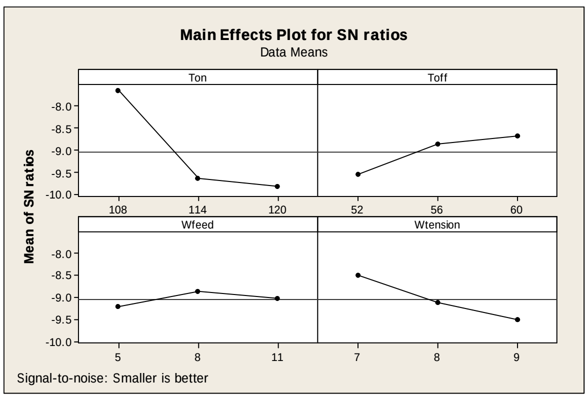

Fig 7. Main effects plots for S/N ratio of Ra.

TABLE X: ANALYSIS OF VARIANCE FOR S/N RATIOS FOR RA.

Source	DF	Seq SS	Percentage of contribution
Ton	2	8.8036	74.302
Toff	2	1.3095	11.052
Wfeed	2	0.1890	1.595
Wtension	2	1.5463	13.010
Total	8	11.8484	100

VI CONCLUSIONS

In the present study, the effect of WEDM process parameters like pulse on time (Ton), pulse off time (Toff), wire feed (Wfeed) and wire tension (Wtension) on machining responses MRR and Ra of copper has been investigated using Taguchi Technique. The optimum process parameters for maximization of MRR are Ton at level 1 (108), Toff at level 2 (56) , Wfeed at level 3 (11) and Wtension at level 3(9). Similarly, the factors Ton at level 1 (108), Toff at level 3 (60), Wfeed at level 2(8) and Wtension at level 1(7) is recommended for minimization Ra. The ANOVA results indicate that Wfeed is the major factor affecting MRR (42.726%) and Ton is the major factor affecting Ra (74.302%).

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