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Optimization of the Process Parameters of Wire Edm of A Hardened Steel 60hrc Component by Taguchi Based Design of Experiments

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ABSTRACT

The Machining parameters tables provided by the machine tool manufacturers often do not meet the operator requirements and sometimes even do not even provide efficient guidelines to manufacturing engineers. Hence, a suitable selection of machining parameters of CNC wire cut electrical discharge machining (EDM) process is necessary.

In this project work we perform an experimental investigation to determine the parameters setting during the machining of Hardened steel 60HRC. The Taguchi method, a powerful tool for experimental design, is used to optimize the CNC-wire cut-EDM parameters. According to the Taguchi quality design Concept, a L_9 (3^4)orthogonal array was used to determine the S/N ratio, and an analysis of variance (ANOVA) and the F-test values were used to indicate the significant machining parameters affecting the machining performance.

From experimental results and through ANOVA and F-test values, the significant factors are determined for each machining performance criteria, such as the metal removal rate, surface roughness, Cylindricity and spark gap (gap width). Considering these significant CNC wire cut-EDM parameters, verification of the improvement in the quality characteristics for machining Hardened steel 60HRC was made with a confirmation test with respect to the chosen initial or reference parameter setting. Mathematical models relating to the machining performance are established using the linear regression for the effective machining of Hardened steel 60HRC. The determined optimal combination of CNC-wire cut-EDM parameters obtained from the study satisfy the real requirement of quality machining of Hardened steel 60HRC in practice.

Keywords— Orthogonal Array, Taguchi, Wire Electro Discharge Machining, Hardened Steel 60Hrc, MRPI,ANOV

1. INTRODUCTION

Technologically advanced industries like aeronautics, nuclear reactors, automobiles, etc have been demanding materials like high temperature resistant alloys having “high strength to weight” ratio. Researchers in the area of material science are developing materials having higher strength, hardness, toughness and other diverse properties. This also needs the development of improved cutting tool materials so that the productivity is not hampered.

It is a well established fact that during conventional machining processes an increase in the hardness of work material results in a decrease in economic cutting speed. It is no longer possible to find tool materials which are sufficiently hard and strong to cut (at economic cutting speeds) materials like titanium, stainless steel, nimonics and similar other high strength temperature resistant alloys, fiber-reinforced composites,stellites,ceramicsand difficult to machine alloys. Production of complex shapes in such materials by traditional methods is still more difficult. Other higher level requirements are better finish, low values of tolerances, higher production rates, etc. To meet such demands, different classes of machining processes have been developed. They are known as advanced machining processes.

These machine tools should not only be able to easily machine the difficult to machine materials to intricate and accurate shapes but also should be adaptable to automation. In order to meet this challenge a number of newer material removal processes have been developed to the level of commercial utilization. These newer methods are also called unconventional in the sense that conventional tools are not employed for metal cutting. Instead energy in its direct form is sued to remove material from the work piece. The range of applications by the newly developed machining processes is determined by the work material properties like electrical and thermal conductivities, melting temperature, electro chemical equivalent, etc. Some of these newly developed processes can also machine work pieces in the areas which are inaccessible for conventional machining processes. The use of these processes is becoming increasingly un avoidable and popular at the shop floor. These processes become still more important when one considers the precision machining and the ultra precision machining. Also high accuracy cannot be achieved in conventional machining processes where the material is removed in the form of chips. However they can be achieved in some of the advanced machining techniques whereby the material is removed in the form of atoms or molecules individually or in groups.

ELECTRIC DISCHARGE MACHINING (EDM)

Whenever sparking takes place between two electrical contacts, a small amount of material is removed from each of the contacts. This fact is realized and the attempts were made to harness and control the spark energy to employ it for useful purposes, say for machining of metals. It was found that the sparks of short duration and high frequency are needed for efficient machining. Further, it was also observed that if the discharge is submerged in dielectric, the energy can be concentrated into a small area.

As soon as the potential across the electrodes crosses the breakdown voltage, the sparking takes place at the point of least electrical resistance. It usually occurs at the smallest inter-electrode gap. After each discharge, the capacitor recharges and the spark appears at the next narrowest gap. Occurrence of each spark generates heat energy which is shared in different modes by work piece, tool, dielectric, debris and other parts of the system.

The dielectric serves some important functions. It cools down the tool and work piece, cleans or flushes away the inter electrode gap and localizes the spark energy into a small cross sectional area. Energy content in each spark and frequency of sparking are governed by the conditions in the inter electrode gap.

GENERAL WORKING PRINCIPLE

EDM is a thermoelectric process in which the heat energy of a spark is used to remove material from the work piece. The work piece and tool should be made of electrically conductive materials. A spark is produced between the two electrodes (tool and work piece) and its location is determined by the narrowest gap between the two. Duration of each spark is very short. The entire cycle time is usually a few micro seconds. The frequency of sparking may be as high as thousands of sparks per second. The area over which a spark is effective (or spark radius) is also very small. However the temperature of the area under the spark is very high. As a result, the spark energy is capable of partly melting and partly vaporizing material from the localized area on both the electrodes. The material is removed in the form of craters which spread over the entire surface of the work piece. Finally the cavity produced in the work piece is approximately the replica of the tool. To have machined cavity as replica of the tool, the tool wear should be zero. To minimize wear of the tool, the operating parameters and polarity should be selected carefully.

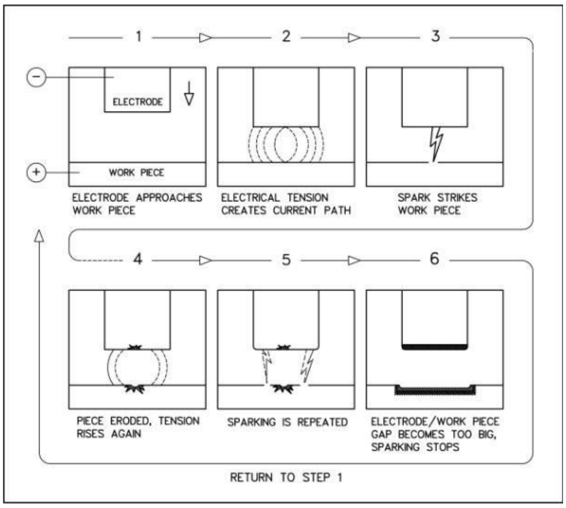


Fig 1.1: Principle of EDM process

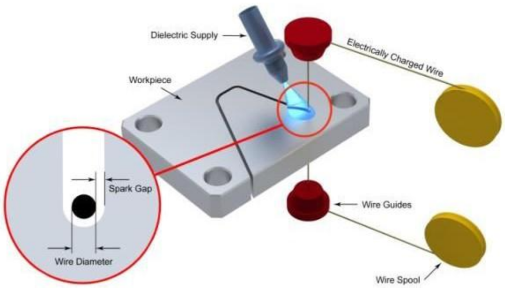


Fig1.2: Wire EDM Process

Features of Wire EDM

1. Forming electrode adapted to product shape is not required.
2. Electrode wear is negligible.
3. Machined surfaces are smooth.
4. Geometrical and dimensional tolerances are tight.
5. Straight holes can be produced to close tolerances.
6. Machine can be operated unattended for a long time at high operating rate.
7. Complex structures can be machined with high machining accuracy.

PROBLEM STATEMENT

In this project work we attempt to optimize the Wire EDM process involved in the machining of the spool bore of the body of an Electro Hydraulic Servo Valve (EHSV). It is an electrically operated valve that controls how hydraulic fluid is ported to an actuator. Servo valves and servo-proportional valves are operated by transforming a changing analogue or digital input signal into a smooth set of movements in a hydraulic cylinder. Servo valves can provide precise control of position, velocity, pressure and force with good post movement damping characteristics. The particular EHSV mentioned here is a type II EHSV that is used primarily in military and space applications. For example it is used in the Prithvi and Agni III missile series for wing tip control. As shown in the Fig: 1.10, the body of the EHSV has three bores, starting from the clockwise direction from the top, they are the nozzle bore, the spool bore and the filter bore. Of the three bores, the spool bore is the most important as this is the bore through which the spool is inserted. It is the position of the spool that is measured using a LVDT and is then demodulated and fed back to the controller where it is compared with the command signal. The controller drives the pilot stage until the error between command signal and feedback signal will be zero. Thus the position of the spool is proportional to the electric command signal. Hence the machining of the spool bore if of a high importance as far as the functionality of the component is considered.

Chapter-2

LITERATURE REVIEW

Y.S Liao et al. [1, 2] devised a method to determine the settings for the machining parameter settings for WEDM process. Based on the Taguchi quality design and the analysis of variance (ANOVA), the significant factors affecting the machining performance such as MRR, gap width ,surface roughness, sparking frequency ,average gap voltage, normal ratio(ratio of normal sparks to total sparks) are determined. By means of regression analysis, mathematical models relating the machining performance and various machining parameters are established.

Mahapatra et al. [3] took measures to improve more than one machining parameter. In rough cutting operation objectives are three fold High MRR, high surface finish & low cutting width (kerf).Using

Taguchi's parameter design significant machining parameters affecting the performance are identified as discharge current, pulse duration, pulse frequency, wire speed, wire tension & dielectric flow. In this study the relationship between control factors & responses like MRR, surface finish and kerf are established by means of non linear regression analysis resulting in a valid mathematical model.

Mu Tian Yan et al.[4] devised a new pulse discriminating and control system for process monitoring and control of the micro wire EDM process. This system functions by identifying four major gap states classified as open circuit, normal spark, arc discharge and short circuit based on based on characteristics of gap voltage waveform.

S. Thamizhmanii et al attempted to analyze the surface roughness produced by turning process on hard martensitic stainless steel by Cubic Boron Nitride cutting tool. The work piece material was hard AISI 440C martensitic stainless steel. Through this paper we have tried to get a better understanding of (hardened) Stainless Steel 440C.

Chapter-3

DESIGN OF EXPERIMENTS ON WIRE EDM

The design of experiment (DOE) is not a simple one step process but is actually a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of product or process performance. Experimental design is a body of knowledge and techniques that assist the experimenter to conduct experiments economically analyze the data and make connections between the conclusions from the analysis and the original objectives of the investigation

A designed experiment is a simultaneous evaluation of parameters (factors) for their ability to affect the resultant average or variability of a particular product or process characteristic. To achieve this in an effective and statistically proper fashion, the levels of the factors are varied in a strategic manner. The results of the particular test combinations are observed, and the complete set of results is analyzed to determine the influential factors and preferred levels and whether increasing or decreasing those levels will potentially lead to further improvement.

MAJOR STEPS INVOLVED IN AN EFFECTIVE DESIGNED EXPERIMENT

1. State the problem or area of concern.
2. Select the objective of the experiment.
3. Select the quality characteristic and measurement system.
4. Identify control and noise factors (Taguchi centric)
5. Select the levels of the factors.
6. Select the appropriate orthogonal arrays (OA).
7. Select interactions that may influence the selected quality characteristics or go back to step 4 (iteration).
8. Assign factors to OA and locate interactions.
9. Conduct tests described by trials in the OA.
10. Analyze and interpret results of the experimental trials.
11. Conduct confirmation experiment.

DEVELOPMENT OF ORTHOGONAL DESIGNS

Dr Genichi Taguchi suggested the use of orthogonal arrays for designing the experiments. He has also developed the concept of linear graph which simplifies the design of OA experiments. These designs can be applied without acquiring advanced statistical knowledge. The main advantage of these designs lies in their simplicity and easy adaptability to more complex experiments involving number of factors with different number of levels. They provide the desired information with the least possible number of trials and yet reproducible results with adequate precision. These methods are usually employed to study the main effects and applied in screening experiments.

The resource difference in terms of the number of experiments conducted between OA and full factorial experimentation is given below.

Table 3.5: Comparison of the number of experiments in full factorial and OA designs

Number of factors	Number of levels	Number of experiments	
		Full factorial	Taguchi
3	2	8	4
7	2	128	8
15	2	32768	16
4	3	81	9
13	3	1594323	27

Selection of orthogonal arrays

The selection of which OA to use predominantly depends on the following factors in order of priority [16]:

- The number of factors and interactions of interest
- The number of levels for the factors of interest
- The desired experimental resolution of cost limitations

The first two items determine the smallest orthogonal array that is possible to use, but this will automatically be the lower resolution lowest-cost experiment. The experimenter may choose to run a larger experiment consisting of a larger OA which will have higher resolution m potential but will be more expensive to complete.

In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors

Chapter 4

EXPERIMENTAL ANALYSIS OF WIRE EDM

4.1 CHARMILLES ROBOFIL 240CC WIRE EDM

The machine used for the machining of the component is a Charmilles ROBOFIL 240CC Wire EDM Machine.

The specifications of the machine are:-

Table 4.1 Charmilles Robofil 240 cc specifications:

1. Machine	
• Operation	CNC Wire EDM
• Manufacturer	Charmilles
• Model	ROBOFIL 240CC
• Type	Submerged Wire Cutting
• Axes	5 (X,Y,Z,U,V)
2. Work Area	
• Max part dimensions	1000 x 550 x 220 mm
• Max part weight	750 kgs
• Level of dielectric	0-220 mm
• Total Volume of dielectric	760 Liters

Fig 4.1: Charmilles ROBOFIL 240CC Wire EDM machine

Source	**DOF**	**Adj SS**	**Adj MS**	**F-Value**	**P.value**	**%**	**Rank of Significance**
A	2	0.5242	0.26208	4.94	0.168	27.68 %	2
C	2	1.0515	0.52574	9.92	0.092	55.57 %	1
D	2	0.3175	0.15874	2.99	0.250	16.75 %	3
Error	2	0.1060	0.05301				
Total	8	1.9992					

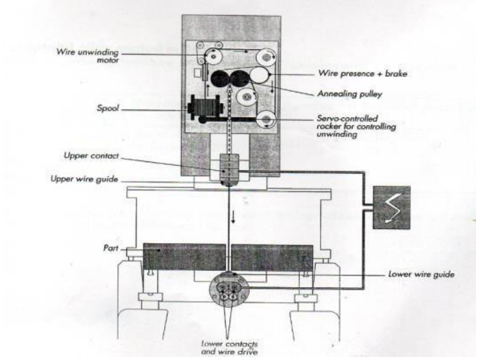


Fig 4.2: Schematic of ROBOFIL 240CC

WORK MATERIAL USED

The different sets of experiments were performed using a 5 axis Charmilles ROBOFIL 240CC wire cut EDM machine, Component Material is Hardened Stainless steel 60HRC.

The electrode (wire) used is an ACTCUT 500 Brass wire of 0.25mm diameter.

Chapter-5

Results and discussion

ANOVA-Analysis of Variance

CYLINDRICITY

The design of the experiment is fully saturated. There is a factor available in every available column in the L9 array. Therefore we have to pool one of our factors to provide an error term with which to calculate the F-ratio. Hence we remove the term that has the smallest value of "Adj MS" from the model and then perform ANOVA using MINITAB 17 software. Removing the term with the smallest value of 'Adj MS" will not affect the result as it has the smallest F-ratio i.e. the weakest effect. The rank of significance is dependent on the '%' column which is obtained from the F-values of the corresponding factors. The rank of significance arranges the factors in their order of significance towards that particular response parameter starting from 1 as the most significant and so on.

For Cylindricity factor 'B' has the lowest "Adj MS" value. Hence we remove B from the table and perform ANOVA for the remaining terms.

Table 5.13: ANOVA Table for Cylindricity

SURFACE ROUGHNESS

For Surface roughness factor 'C' has the lowest "Adj MS" value of 0.004015.Hence we remove C from the table and perform ANOVA for the remaining terms.

Table 5.14: ANOVA Table for Surface roughness

MRR

For MRR, the factor "C" has the lowest 'Adj MS" value of 0.000015.hence we remove C from the table and perform ANOVA for the remaining terms.

Source	**DOF**	**Adj SS**	**Adj MS**	**F-Value**	**P.value**	**%**	**Rank of Significance**
A	2	0.030696	0.015348	3.82	0.207	50.93%	1
B	2	0.008089	0.004044	1.01	0.498	13.47%	3
D	2	0.021452	0.010726	2.67	0.272	35.60%	2
Error	2	0.008030	0.004015				
Total	8	0.068267					

Table 5.15: ANOVA Table for MRR

Source	**DOF**	**Adj SS**	**Adj MS**	**F-Value**	**P.value**	**%**	**Rank of Significance**
A	2	0.000068	0.000034	2.18	0.314	16.35%	2
B	2	0.000034	0.000017	1.08	0.480	8.10%	3
D	2	0.000312	0.000156	10.07	0.090	75.54%	1
Error	2	0.000031	0.000015				
Total	8	0.000444					

SPARK GAP

For Spark Gap, the factor D has the lowest “Adj MS” of 0.000.Hence we remove D from the table and perform ANOVA for the remaining terms.

Table 5.16: ANOVA Table for Spark Gap

Source	**DOF**	**Adj SS**	**Adj MS**	**F-Value**	**P.value**	**%**	**Rank of Significance**
A	2	0.000002	0.000001	10.69	0.086	42.50%	1
B	2	0.000001	0.000001	7.00	0.125	27.83%	2
C	2	0.000001	0.000001	7.46	0.118	26.66%	3
Error	2	0.000000	0.000000				
Total	8	0.000005					

MATHEMATICAL MODELS

The mathematical models are created using linear regression in MINITAB 17 software.

The regressive analysis gives us the mathematical equation

$$E = 2.4 + 0.027\ A - 0.100\ B + 0.0412\ C + 0.123\ D$$

Here E = Theoretical value of Cylindricity

A, B, C, D = Input Parameters

SURFACE ROUGHNESS

The regressive analysis gives us the mathematical equation

$$G = 5.200 - 0.0705\ A - 0.0867\ B - 0.00400\ C - 0.2226\ D$$

Here G = Theoretical value of Surface Roughness

A, B, C, D = Input Parameters

MRR

The regressive analysis gives us the following mathematical equation

$$F = 0.1566 - 0.00225\ A + 0.00465\ B - 0.000224\ C + 0.02194\ D$$

Here F = Theoretical value of MRR

A, B, C, D = Input Parameters

SPARK GAP

The regressive analysis gives us the following mathematical equation

$$H = -0.1578 + 0.000575\ A + 0.000500\ B + 0.000046\ C + 0.000538\ D$$

Here H = Theoretical value of Spark Gap

A, B, C, D = Input Parameters

CONFIRMATION TESTS.

CYLINDRICITY

- From the results of the experiments performed and the data obtained (chapter 4-5), we can determine the optimum machine setting for best Cylindricity.

•The required setting is

Table 5.17: Optimum settings for Cylindricity

•The confirmation test has to be performed at the setting A1B3C1D2

•Result for the confirmation experiment for Cylindricity is:-

SURFACE ROUGHNESS

•From the results of the experiments performed and the data obtained we can determine the optimum machine setting for best surface roughness.

•The required setting is

Table 5.18: Results of confirmation experiments for Cylindricity

	Initial Machining Parameters	**Optimal Machining Parameters**		**Improvement in S/N ratio over original setting**	**Improvement over original setting**
		Predicted(Theoretical)	**Experimental**		
Setting Level	$A_1B_1C_1D_1$	$A_1B_3C_1D_2$	$A_1B_3C_1D_2$		
Cylindricity (µ m)	4.71	4.41	4.36		7.43%
S/N Ratio	-13.4604	-12.8888	-12.7897	0.6707	

•The confirmation test has to be performed at the setting A3B2C2D2

•Results from the confirmation test for Surface Roughness is:

Results of confirmation experiments for surface roughness

Initial Machining Parameters Optimal Machining ParametersImprovement in S/N ratio over original setting Improvement over original setting.

Table5.20: Results of confirmation experiments for surface roughness

	Initial Machining Parameters	**Optimal Machining Parameters**		**Improvement in S/N ratio over original setting**	**Improvement over original setting**
		Predicted(Theoretical)	**Experimental**		
Setting Level	$A_1B_1C_1D_1$	$A_3B_2C_2D_2$	$A_3B_2C_2D_2$		
Surface Roughness	0.84,0.84,0.88	0.5342	0.54,0.52,0.50		39.06%
S/N Ratio	1.3757	5.4491	5.6756	4.2999	

MRR

•From the results of the experiments performed and the data obtained we can determine the optimum machine setting for best MRR

•The required setting is

Optimum settings for MRR

Factor	Level	Value of Parameter at Corresponding Level
A	2	49
B	3	7.5
C	1	40
D	2	1.5

•The confirmation test has to be performed at the setting A2B3C1D2

•Result for the confirmation experiment for cylindricity is:-

Table 5.22: Results of confirmation experiments for MRR

	Initial Machining Par	**Optimal Machining Parameters**		**Improvement in S/N ratio over**	**Improvement over original setting**
		Predicted(Theoretical)	**Experimental**		

	ameters			**original setting**	
Setting Level	$A_1B_1C_1D_1$	$A_2B_3C_1D_2$	$A_2B_3C_1D_2$		
MRR (mm^3/s)	0.08954	0.105175	0.105455		17.77%
S/N Ratio	-20.9597	-19.5617	-19.5837	1.376	

SPARK GAP

- From the results of the experiments performed and the data obtained we can determine the optimum machine setting for best Spark Gap
- The required setting is
- Table 5.23: Optimum settings for spark gap

Factor	**Level**	**Value of Parameter at Corresponding Level**
A	3	50
B	3	7.5
C	3	60
D	3	1.6

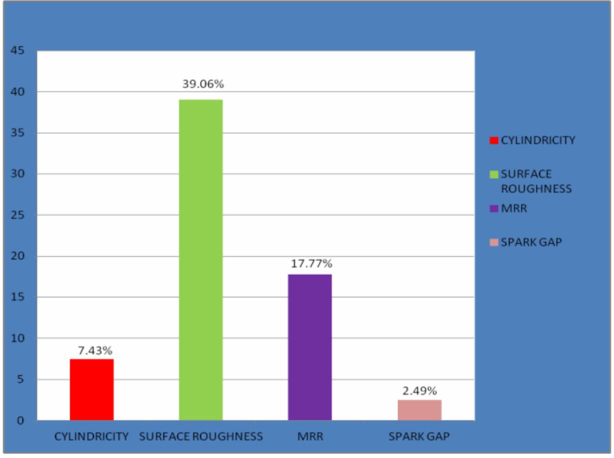
- The confirmation test has to be performed at the setting $A_3B_3C_3D_3$
- Result for the confirmation experiment for Spark Gap is:-
- Table 5.24: Results of confirmation experiments for spark gap

	Initial Machining Parameters	**Optimal Machining Parameters**		**Improvement in S/N ratio over original setting**	**Improvement over original setting**
		Predicted(Theoretical)	**Experimental**		
Setting Level	$A_1B_1C_1D_1$	$A_3B_3C_3D_3$	$A_3B_3C_3D_3$		
Spark Gap	-0.12	-0.1234	-0.1214		2.49 %

	45				
S/N Ratio	18.096	18.173	18.315	0.219	

Table 5.25 Percentage of Improvement in result

S.l No	Name of the factor	Percentage of improvement
1	Cylindricity	7.43%
2	Surface Roughness	39.06%
3	MRR	17.17%
4	Spark Gap	2.49%



Graph 5.9 Percentage of Improvement in results

For the given Machining Parameters maximum improvement observed in surface roughness

CONCLUSION

On the basis of experimental results, the calculated S/N ratios, the analysis of ANOVA, F-test values, confirmation tests and the regression analysis, the following conclusions are drawn for the effective machining of Hardened Stainless Steel 60HRC by the CNC-wire cut EDM process:

1. For optimum Cylindricity (decreased) the recommended parametric combination is $A_1B_3C_1D_2$ where A_1 is 48.1 V, B3 is 7.5μs, C1 is 40 KHz and D_2 is 1.5N.

2. For optimum surface roughness (decreased) the recommended parametric combination is $\mathbf{A_3B_2C_2D_2}$ where A_3 is 50 V, B_2 is 7µs, C2 is 50 KHz and D_2 is 1.5 N.
3. For optimum MRR (increased), the recommended parametric combination is $\mathbf{A_2B_3C_1D_2}$where A_2 is 49 V, B_3 is 7.5µs, C_2 is 40 KHz and D_2 is 1.5 N.
4. For optimum Spark Gap (decreased) the parametric combination is $\mathbf{A_3B_3C_3D_3}$where A_3 is 50V, B3 is 7.5µs, C_3 is 60 KHz and D_3 is 1.6N.
5. The control parameters in order of their significance for affecting Cylindricity are frequency, set value of average machine voltage, wire tension and interval between two pulses.
6. The control parameters in order of their significance for affecting surface roughness are set value of average machine voltage, wire tension, interval between two pulses and frequency.
7. The control parameters in order of their significance for affecting MRR are wire tension, set value of average machine voltage, Interval between two pulses and frequency.
8. The control parameters in order of their significance for affecting spark gap are set value of average machine voltage, interval between two pulses, frequency and wire tension.
9. Mathematical models for different machining performance characteristics of the wire EDM process have been proposed by means of linear regression and are as follows.
   - Cylindricity = 2.4 + 0.027 A - 0.100 B + 0.0412 C + 0.123 D
   - Surface roughness = 5.200 - 0.0705 A - 0.0867 B - 0.00400 C - 0.2226 D
   - MRR = 0.1566 - 0.00225 A + 0.00465 B - 0.000224 C + 0.02194 D
   - Spark gap = -0.1578 + 0.000575 A + 0.000500 B + 0.000046 C + 0.000538 D

     Where A= set value of average machine voltage, B= interval between two pulses, C= frequency and D= wire tension
10. The ANOVA analysis can be made more accurate and significance of all 4 factors can be calculated by increasing the OA from L_9 to L_{18} or L_{27}.
11. By setting the machine to the parametric combination of $A_1B_3C_1D_2$ instead of the initial setup of $A_1B_1C_1D_1$ the Cylindricity has decreased from 4.71µ m to 4.36µm.An optimization of **7.43%**
12. By setting the machine to the parametric combination of $A_3B_2C_2D_2$ instead of the initial setup of $A_1B_1C_1D_1$ the surface roughness has decreased from an average of 0.8533µm to an average of 0.52µ m .An optimization of**39.06%.**
13. By setting the machine to the parametric combination of $A_2B_3C_1D_2$ instead of the initial setup of $A_1B_1C_1D_1$ the MRR has increased from 0.089540 mm^3/s to 0.105455 mm^3/s. An optimization of **17.77%.**
14. By setting the machine to the parametric combination of $A_3B_3C_3D_3$ instead of the initial setup of $A_1B_1C_1D_1$ the Spark Gap has been decreased from 0.1245 to 0.1214.Hence optimized by **2.49%.**

FUTURE SCOPE:

- Interactions between response parameters can be used to find the optimal parametric arrangement for a combination of response parameters all taken at once.

- Similar process can be applied to other manufacturing techniques after identifying their
  Signal and Noise factors.

- The mathematical models obtained can be combined with Operational research techniques to obtain a range of working conditions for the required output.

- This work can be extended by considering a combination of fuzzy control, Rey relational analysis with Taguchi's Orthogonal Array techniques, Response Surface methodology technique.

- Application of Genetic Algorithm can help obtain a global parametric arrangement.

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