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Comparative Analysis of Soft and Hard Brass Wire Electrode on WEDM Machining Performance Parameters Using Die Steel D7

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Abstract

Die Steel AISI D7 is an important material for tool and dies mostly because of its high hardness, strength and wears resistance over a wide range of temperature. Die Steel AISI D7 is high carbon-high chromium die steel with added carbon and vanadium for unexcelled abrasion resisting qualities. It was developed especially for applications involving extreme abrasive wear.It has good non deforming Properties and wear resistance and but cannot be fabricated easily by conventional machining techniques. Since WEDM (Wire electrical discharge machining) has been shown to be a versatile method for machining difficult-to-work materials and suitable in conforming die Steel AISI D7, therefore WEDM process is chosen as a method to machine die Steel AISI D7 in this study.

Keywords: *WEDM, Soft and Hard Brass Wire.*

1. Introduction

This paper attempts to investigate the effect of WEDM parameters on the surface integrity of die steel AISI D7, namely the surface finish (Ra), Cutting Speed (Cs), and Material removal rate (MRR) by using soft and hard brass wire electrode. The main focus in this study is on comparative analysis of soft and hard brass wire electrode on WEDM performance parameters (surface finish, Cutting Speed, and Material removal rate).The machining parameters are the input parameters of WEDM process, namely pulse on time (Ton), pulse off time (T off), peak current (IP), wire feed rate (WF), and wire tension (WT), which is believed have great influence to performance of machining. Classical Design of Experiment (DOE) is used to investigate the effect of machining variables and to establish the relationship of certain responses.

Taguchi design methodology has been chosen for design of experiment and L16 orthogonal array has been selected for present study. Two different sets of experiments based on L16 OA have been designed using two different machining wires (Soft brass wire electrode for first set of experiment and Hard brass electrode for second set of experiment).In this investigation the machining is done by WEDM on two specimens of same size with same parameters by using soft and hard brass wire electrode. Main effect plot have been used to find the significant process parameters and their effect on the response variables. The comparative analysis of soft and hard brass wire electrode have been optimized using response curves and differentiated on the basis of rank which is given by response table. The comparative analysis of soft and hard brass wire electrode have been also investigated by experimental results.

2. Literature Review

Spedding and Wang, (1997) developed mathematical models to predict material removal rate and surface finish while machining D-2 tool steel at different machining conditions. It was found that there is no single combination of levels of the different factors that can be optimal under all circumstances [1].**Huang et. al. (1999)** investigated experimentally the effect of various machining parameters on the gap width, surface roughness and the depth of white layer on the machined work piece (tungsten carbide) surface[2]. **Murphy and Lin (2000)** developed a combined structural-thermal model using energy balance approach to describe the vibration and stability characteristics of an EDM wire. High-temperature effects were also included resulting from the energy discharges[3].**Yan et. al. (2001)** presented a feed forward neural network using a back propagation learning algorithm for the estimation of the work piece height in WEDM[4].**Lee et al. (2003)** cracks normally exist in the recast layer, initiating at its surface and traveling down perpendicularly towards the parent material. In the vast majority of cases, the cracks terminate within the white layer or just on the interface of the white layer and the parent material. Sometimes the cracks also may observe within the crater as the result of thermal stress during discharge. Surface roughness usually caused by uneven fusing structure, globules of debris, shallow craters, pockmarks, voids, cracks and recast layer[5]. **Ho, K.H. et. al. (2004)** reviewed the vast array of research work carried out from the spin-off from the EDM process to the development of the WEDM. It reported on the WEDM research involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity. The paper also highlighted the adaptive monitoring and control of the process investigating the feasibility of the different control strategies of obtaining the optimal machining conditions [6]. **Ramasawmy et.al (2005)** described the multi objective optimization of the WEDM process using parametric design of Taguchi methodology. The effect of various machining parameters such as pulse on time, wire tension, delay time, wire feed speed, and ignition current intensity has been studied in machining of heat-treated tool steel. It was identified that the pulse on time and ignition current intensity has influence more than the other parameters. Moreover, the multiple performance characteristics such as material removal rate, surface roughness, and wire wear ratio for the WEDM process could be improved by setting the various process parameters at their optimal levels [7].**Mahapatra and Patnaik (2007)** developed relationships between various process parameters and responses like MRR, SR and kerf by means of non-linear regression analysis and then employed genetic algorithm to optimize the WEDM process with multiple objectives[8]. **Mohammadi et al.(2008)** investigated the effect of various process parameters for Turning WEDM such as power, time-off, voltage, servo, wire tension, wire speed along with rotational speed on surface roughness and roundness. 1.731 cemented steel was chosen as work piece material. Taguchi standard orthogonal array was chosen for the design of experiments and ANOVA was used for determining level of importance of machining parameters on surface roughness and roundness. Experimentation result shows that power has significant effect on surface roughness and other factors do not impact the surface roughness and other factor do not have significant effect on roundness. Factors affecting the surface roughness are power, wire speed, voltage, wire tension, time-off, servo, and rotational speed affect the surface roughness. If comparison is done then it has been shown by experiments that wire speed, power, and servo effects roundness more significantly than time-off, voltage, wire tension, and rotational speed. Thus a multiple linear regression equation had been derived for surface roughness[9].**Patil and Brahmankar(2010)** investigated electrical and non electrical process parameters for machining metal matrix composite. The metal matrix composite chosen for this experiment is reinforced aluminum matrix composite and wire used is a brass wire of 0.25 mm diameter. Process parameters that have been chosen were reinforcement percentage current, pulse on-time, off time, servo reference voltage, maximum feed speed, wire speed, flushing pressure and wire tension whereas the response parameters were cutting speed surface finish, and kerf width. Taguchi design methodology has been used to study the effect of performance parameters on the response parameters. It has been observed that WEDM is a good process to machine metal matrix composites and reinforcement percentage current and pulse on time have significant effect on cutting rate, surface finish, and kerf width. Wire breakages have been observed for higher cutting speeds and also wire shifting leads to deterioration of the machined surface [10].**Jatinder Kapoor et.al (2011)** presents the results of the effect of Cryogenic treated brass wire electrode on the surface of an EN-31 steel machined by WEDM. Full factorial experimental design strategy is used in the experimentation. Three process parameters, namely type of wire electrode (untreated and cryogenic treated brass wire electrodes), Pulse width, and wire tension have been considered. The process performance is measured in terms of surface roughness (SR). ANOVA results indicated that all the process parameters have significant effect on SR. Scanning electron microscopy highlighted the important features of WEDMed surfaces with cryogenic treated and untreated brass wire electrode. Surface roughness is improved with cryogenic treated brass wire electrode [11].**Harpreet Singh and Amandeep Singh(2012)** studed that wear behaviour AISI D3 Die steel in EDM and compare the tool wear rate of cryogenic treated cooper and brass electrode with simple copper and brass electrode on machining of AISI D3 die steel using current setting as 4A and 8A. The electrolyte is used kerosene oil. Copper electrode is best electrode for high material removal rate. But cryogenic treated copper electrode has very low tool wear as compared to cooper electrode [12].

S.Sivanaga Malleswara Rao et.al (2013) concluded that the influence of parameters like discharge current, job thickness, on the machining criteria such as cutting speed, spark gap, material removal rate are determined. The results are useful in setting the parameters required for quality cuts on HC-HCr die steel. Suitable parameters can be selected for machining with the 0.25mm diameter wire. The mathematical relations developed are much more beneficial for machine settings, to estimate the cutting time, cost of machining and accuracy of cutting for any size of the job within machine range. The maximum error obtained in the calculated values and experimental values are less than 2%. These results will be useful to make the Wire EDM system to be efficiently utilized in the modern industrial applications like die & tool manufacturing units for parametric setting, machining time, cost calculations and also for process planning [13].

3. Objectives

To evaluate the performance of Wire Electro-Discharge Machining (WEDM) on of die Steel D7 using soft and hard brass wire electrode as tool with respect to various response variables such as material removal rate, surface finish and cutting speed and to determine significant process parameters using Taguchi‟s technique and Comparative analysis of soft and hard brass wire electrode on WEDM performance parameters (Surface Roughness, Cutting Speed, Material removal Rate).

CHEMICAL COMPOSITION OF DIE STEEL D7

(Table no: 1.1)

Elements	Percentage of elements
Carbon	2.30%
Silicon	.40%
Manganese	.40%
Chromium	12.50%
Vanadium	4.00%
Molybdenum	1.10%

In this paper, five design factors have been decided which consist of, pulse on time, pulse off time, peak current, wire feed rate, wire tension. These five factors will be analyzed by using classical method and 16 experiments will be carried out. In Wire-cut EDM process, there are interacting effects among design factors so this method will make the experimental results lack responsibility. Therefore the design of experiment (DOE) is required in this work because reproducible result can be achieved; meaning the conclusion and recommendations derived from the results of the analysis the measured performances on the experiments are possible for other people to repeat the experiment at other times and obtain similar result.

4. Parameters

A large number of input process parameters can be varied in the WEDM process, each having its own impact on output parameters such as Material Removal Rate (MRR), surface roughness, Cutting Speed etc. Various input parameters are:

a. Pulse on-time
b. Pulse off-time
c. Peak current
d. Servo voltage
e. Wire tension
f. Wire feed
g. Dielectric flushing pressure

The effect of each of these parameters on WEDM process is discussed in the literature review in detail. It is also known from the previous research works that out of the above listed parameters, three parameters directly affect the MRR, surface roughness and Cutting Speed in WEDM. These three parameters are peak current, pulse on-time, pulse off-time. Out of these parameters, three parameters have been investigated thoroughly in this research work. Servo voltage along with other parameters has been kept constant for the whole experiment. Along with these three parameter we select two more parameter Wire feed and Wire tension. So we select five parameter for Experimental work. The levels of five parameters (i.e. pulse on, pulse off & peak current, Wire feed and Wire tension) for the experimentation have been decided from the machine software (Minitab).

4.1 Selection of Process Parameters

In order to identify the process parameters that may affect the machining characteristics of WEDM machined parts an Ishikawa cause and effect diagram was constructed and is shown in Figure 3.5. The input process parameters and output characteristics selected from Ishikawa cause and effect diagram for the present work are shown in Figure 3.5.

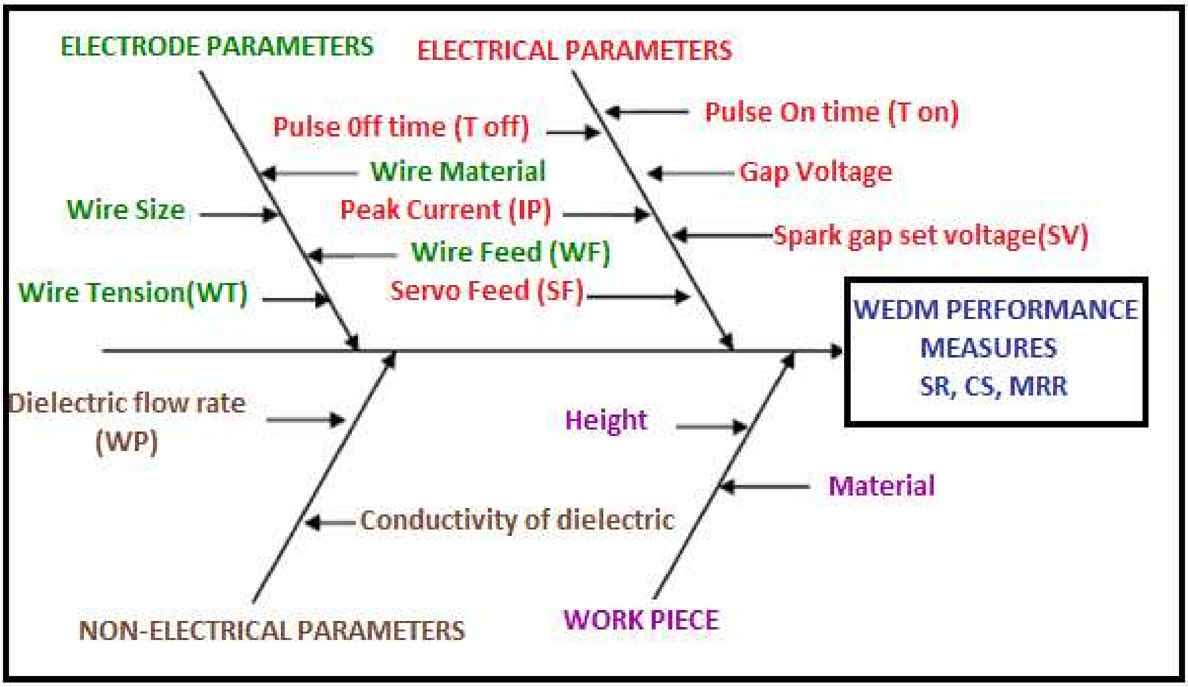

Figure no 1.1: Ishikawa Cause and Effect Diagram for WEDM Process

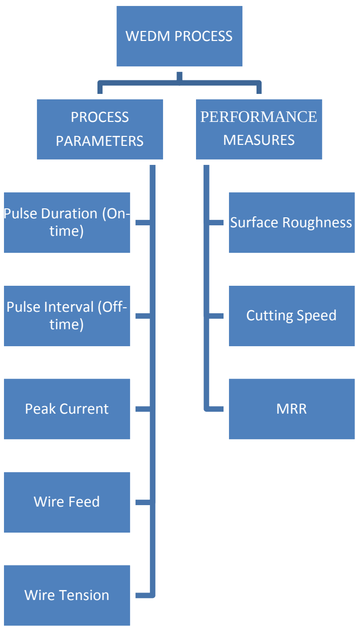

Figure no 1.2: Selected Process Parameters and Performance Measures of WEDM

4.2 Selection of Range Of Parameters

Based on the literature there are around fifteen machining factors that are directly involved in WEDM operation. Some of the factors are significant in influenced the machining characteristics and some are less. The literatures on the significance affect of these parameters to the machining process already have been discussed in Chapter 2. Five cutting parameters have been identified by the aid of previous researches and literature reviews affecting the die Steel D7 machining performance; pulse on time (Ton), pulse off time (T off), peak current (IP), wire feed (WF) and wire tension (WT). While other parameters are held constant. The setting of the machining parameters is given in Table 4.1 All the values indicate in this table is based on literature survey and supervised by the technician in-charged. However, the capabilities of the machine available will be a major consideration in this project. The experiments were carried by varying the process parameters e.g. pulse on time (Ton), pulse off time (T off),peak current (IP), wire feed (WF) and wire tension (WT) to study their effect on output parameters e.g. surface roughness, cutting speed and MRR. The ranges of these process parameters are given in Table 3.4**.** From these ranges of the process parameters, different levels of process parameters would be selected for Taguchi experimental design.

Table no 1.2: level of the machining parameters

Machining parameters	**LEVELS**			
	1	2	3	4
Pulse ON time, (μs)	108	116	124	131
Pulse OFF Time, (μs)	20	30	40	50
Peak Current, (IP)	200	210	220	230
Wire Feed, (WF)	2	4	6	8
Wire Tension, E (WT)	6	7	8	9

In this study, the full factorial DOE was used as a tool for the overall research design and analysis. Design of experiment includes determining controllable factors and the levels to be investigate. While, analysis of results is to determine the best possible factor combination from individual factor influences. Lastly, confirmation tests would be carried out as a proof to the optimum results studied.

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analyzed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed. The advantages of design of experiments are as follows:

- Numbers of trials is significantly reduced.
- Important decision variables which control and improve the performance of the product or the process can be identified.
- Optimal setting of the parameters can be found out.
- Qualitative estimation of parameters can be made.
- Experimental error can be estimated.
- Inference regarding the effect of parameters on the characteristics of the process can be made.

In the present work, the Taguchi's method, and design of experiment have been used to plan the experiments and subsequent analysis of the data collected.

4.3 TAGUCHI EXPERIMENTAL DESIGN AND ANALYSIS

4.3.1 Taguchi's Philosophy

Taguchi's comprehensive system of quality engineering is one of the greatest engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production and market place. Shop-floor techniques provide cost-based, real time methods for monitoring and maintaining quality in production. The farther upstream a quality method is applied, the greater leverages it produces on the improvement, and the more it reduces the cost and time. Taguchi's philosophy is founded on the following three very simple and fundamental concepts :

- Quality should be designed into the product and not inspected into it.
- Quality is best achieved by minimizing the deviations from the target. The product or process should be so designed that it is immune to uncontrollable environmental variables.
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi proposes an "off-line" strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. He observes that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Taguchi recommends a three-stage process: system design, parameter design and tolerance design. In the present work Taguchi's parameter design approach is used to study the effect of process parameters on the various responses of the WEDM process.

The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has greatest influence on the performance and the least variation from the target of the design. The effect of various parameters (work piece material, electrode, pulse on time, pulse off time, current and powder) and some of the effects of interactions between the main factors were also be studied using parameterization approach developed by Taguchi.

4.4 Experimental Design Strategy

4.4.1 Selection of orthogonal array (OA)

OA plays a critical part in achieving the high efficiency of the Taguchi method. OA is derived from factorial design of experiment by a series of very sophisticated mathematical algorithms including combinatory, finite fields, geometry and error- correcting codes. The algorithms ensure that the OA to be constructed in a statistically independent manner that each level has an equal number of occurrences within each column; and for each level within one column, each level within any other column will occur an equal number of times as well. Then, the columns are called orthogonal to each other. OA‟s are available with a variety of factors and levels in the Taguchi method. Since each column is orthogonal to the others, if the results associated with one level of a specific factor are much different at another level, it is because changing that factor from one level to the next has strong impact on the quality characteristic being measured. Since the levels of the other factors are occurring an equal number of times for each level of the strong factor, any effect by these other factors will be ruled out.

Taguchi‟s orthogonal arrays are experimental designs that usually require only a fraction of the full factorial combinations. The arrays are designed to handle as many factors as possible in a certain number of runs compared to those dictated by full factorial design. The columns of the arrays are balanced and orthogonal. This means that in each pair of columns, all factor combinations occur same number of times. Orthogonal designs allow estimating the effect of each factor on the response independently of all other factors. Once the degrees of freedom are known, the next step, selecting the orthogonal array (OA) is easy. The number of treatment conditions is equal to the number of rows in the orthogonal array and it must be equal to or greater than the degrees of freedom. The interactions to be evaluated will require an even larger orthogonal array. Once the appropriate orthogonal array has been selected, the factors can be assigned to the various columns.

Taguchi recommends orthogonal array (OA) for lying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments.

The selection of orthogonal array depends on:

1. The number of factors or Selection of process parameters and or interactions to be evaluated.
2. The number of levels for the factors of interest or Selection of number of levels for the selected parameters.

The determination of which parameters to investigate hinges upon the product or process performance characteristics or responses of interest .Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are

1. Brainstorming
2. Flow charting
3. Cause-Effect diagrams

Taguchi method the results of the experiments are analyzed to achieve one or more of the following objectives.

- To establish the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and interactions.
- To estimate the response under the optimum condition.

The Taguchi method apparently has the following strengths:

- Consistency in experimental design and analysis.
- Reduction of time and cost of experiments.
- Robustness of performance without removing the noise factors.

The standard Four level:

1. Four level arrays: L4, L8, L12, L16,L25,L27and L32
   The Single level arrays for 5 parameters (MINTAB -15) are:
   Run Level **Columns
   L16 4**5

Table no 1.3: Single level orthogonal array L16

Experiment Number	Machining Parameter				
	Ton (µs)	Toff (µs)	IP(amp)	WF(mm/min)	WT(gram)
1	108	20	200	2	6
2	108	30	210	4	7
3	108	40	220	6	8
4	108	50	230	8	9
5	116	20	210	8	8
6	116	30	200	6	9
7	116	40	230	4	6
8	116	50	220	2	7
9	124	20	220	4	9
10	124	30	230	2	8
11	124	40	200	8	7
12	124	50	210	6	6
13	131	20	230	6	7
14	131	30	220	8	6
15	131	40	210	2	9
16	131	50	200	4	8

The optimum condition is identified by studying the main effects of each of the parameters. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. First,the standard approach, where the results of a single run or the average of repetitive runs are processed through main effect analysis.

The second approach which Taguchi strongly recommends for multiple runs is to use signal- to- noise ratio (SN) for the same steps in the analysis. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response (transform of raw data) of the experiment. Taguchi recommends the use of OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into experiment. It is sufficient to generate repetitions at each experimental condition of the controllable parameters and analyze them using an appropriate S/N ratio.

In the present investigation, the raw data analysis and S/N data analysis have been performed. The effects of the selected

WEDM process parameters on the selected quality characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the quality characteristics has been established through S/N data analysis aided by the raw data analysis.

4.4.2 Signal to Noise Ratio

The parameters that influence the output can be categorized into two classes, namely controllable (or design) factors and uncontrollable (or noise) factors. Controllable factors are those factors whose values can be set and easily adjusted by the designer. Uncontrollable factors are the sources of variation often associated with operational environment. The best settings of control factors as they influence the output parameters are determined through experiments.

The experimental observations are further transformed into a signal-to-noise (S/N) ratio. There are several (S/N) ratios available depending on objective of optimization of the response. Taguchi method is used to analysis the result of response of machining parameter for smaller is better criteria. Therefore, "SB" for the surface roughness was selected for obtaining optimum machining performance characteristics. The loss function (L) for objective of SB is defined as follows, where Ysr(i) represent response for surface roughness and 'n' denotes the number of experiments. The S/N ratios for surface roughness are calculated as given in equation.

$$\mathrm{LSB} = [1/\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} 1/\mathrm{y}_{\mathrm{sr(i)}}^{2}]$$

The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below.

S/N ratio for Surface roughness = -10 $\log_{10}$ (LSB)

Therefore, "HB" for the Cutting Speed was selected for obtaining optimum machining performance characteristics. The loss function (L) for objective of HB is defined as follows, where Ycs(i) represent response for cutting speed and 'n' denotes the number of experiments. The S/N ratios for cutting speed are calculated as given in equation.

$$\mathrm{LHB} = [1/\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} 1/\mathrm{y}_{\mathrm{cs(i)}}^{2}]$$

The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below.

S/N ratio for cutting speed = -10 $\log_{10}$ (LHB)

Therefore, "HB" for the MRR was selected for obtaining optimum machining performance characteristics. The loss function (L) for objective of HB is defined as follows, where YMRR(i) represent response for material removal rate and 'n' denotes the number of experiments. The S/N ratios for material removal rate are calculated as given in equation.

$$\mathrm{LHB} = [1/\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} 1/\mathrm{y}_{\mathrm{mrr(i)}}^{2}]$$

The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below.

S/N ratio for MRR = -10 $\log_{10}$ (LHB).

SN Ratio for Response Characteristics

The parameters that influence the output can be categorized in two categories, controllable factors and uncontrollable factors. The control factors that may contribute to reduced variation can be quickly identified by looking at the amount of variation present in response. The uncontrollable factors are the sources of variation often associated with operational environment. For this experimental work, response characteristics are given in the table: 1.4

Table no: 1.4 Response Characteristics

RESPONSE NAME	RESPONSE TYPE	UNITS
Material Removal Rate	Higher the better	g/min
Cutting Speed	Higher the better	mm/sec
Surface Roughness	Smaller the better	μm

4.5 SOFTWARE SELECTION & INTRODUCTION

4.5.1 Taguchi design of experiments with MINITAB

MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB calculates response tables and generates main effects for:-

1. Signal-to-noise ratios (S/N ratios) vs. the control factors
2. Means (static design) vs. the control factors

A Taguchi design or an orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a five factor, Single level setup is chosen with a total of sixteen numbers of experiments to be conducted and hence the OA L16 was chosen.

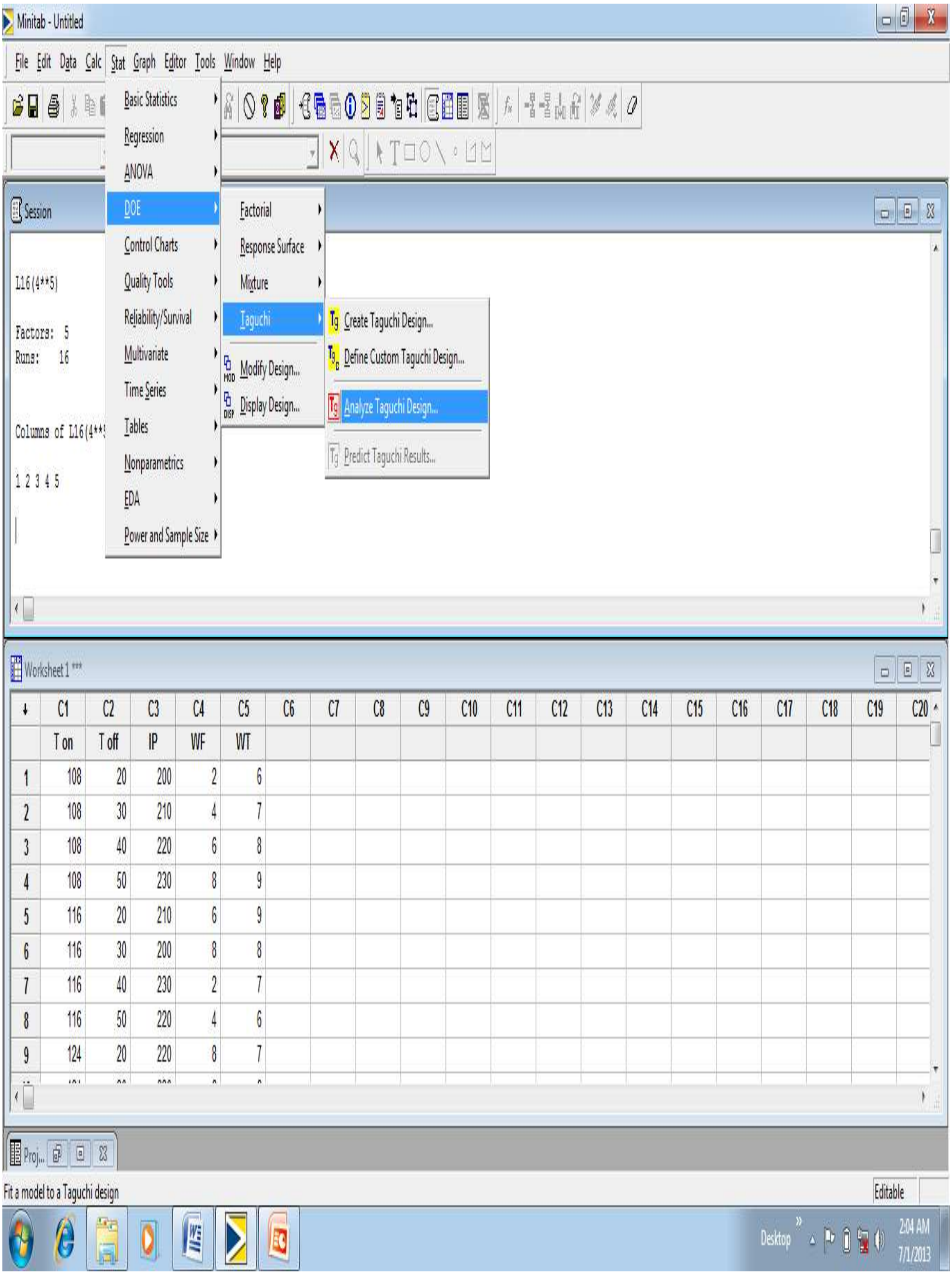

Figure 1.3: illustration of MINITAB

5. Comparison of Soft and Hard Wire on the Basis of Rank Table

The following results found from response table

(Table no 1.5: Rank Table of soft and hard wire electrode)

COMPARISON OF SOFT AND HARD WIRE ON THE BASIS OF RANK WHICH WE FOUND FORM RESPONCE TABLE OF HARD AND SOFT WIRE

	SOFT WIRE		HARD WIRE	
	RANK	PARAMETER	RANK	PARAMETER
S.R	1	T off	1	WF
	2	WT	2	T on
	3	T on	3	IP
	4	IP	4	T off
	5	WF	5	WT
C.S	1	T on	1	T on
	2	WT	2	WF
	3	T off	3	IP
	4	IP	4	T off
	5	WF	5	WT
M.R.R	1	T off	1	T on
	2	T on	2	IP
	3	WF	3	WF
	4	WT	4	T off
	5	IP	5	WT

5.1 Comparison of Surface Roughness of Soft and Hard Wire on The Basis Of Rank Table

Surface roughness of Soft wire electrode: From the Rank table we can see that most significant factor in case soft wire electrode is T off and wire tension. T off have rank 1 so most significant factor is T off. The reason behind this is that when the pulse off time increases the effect of spark is less and due to which surface roughness is less. T on, IP and WF are less significant parameter.

Surface roughness of hard wire electrode: From the Rank table we can see that most significant factor in case hard wire electrode is WF and T on. WF has rank 1 so most significant factor is WF. The reason behind this is that the wire is hard and due to hardness of wire the effect of wire feed is highly affected the surface roughness. IP, T off and WT are less significant parameter.

5.1.2 Comparison of Cutting Speed of Soft and Hard Wire on The Basis Of Rank Table

Cutting speed of Soft wire electrode: From the Rank table we can see that most significant factor in case soft wire electrode is T on and wire tension. T on have rank 1 so most significant factor is T on. The reason behind this is that when the pulse on time increases the effect of spark is more and due to which cutting speed is increase. T off, IP and WF are less significant parameter.

Cutting speed of hard wire electrode: From the Rank table we can see that most significant factor in case hard wire electrode is T on and wire feed. T on have rank 1 so most significant factor is T on. The reason behind this is that when the pulse on time increases the effect of spark is more and due to which cutting speed is increase. IP, T off and WT are less significant parameter.

5.1.3 Comparison of Material Removal Rate of Soft and Hard Wire On The Basis Of Rank Table

Material removal rate of Soft wire electrode: From the Rank table we can see that most significant factor in case soft wire electrode is T off and T on and wire tension. T off have rank 1 so most significant factor is T off. The reason behind this is that when the pulse off time decrease the effect of spark is more and due to which material removal rate is increase. WF, WT and IP are less significant parameter.

Material removal rate of hard wire electrode: From the Rank Table we can see that most significant factor in case hard wire electrode is T on and IP. T on have rank 1 so most significant factor is T on. The reason behind this is that when the pulse on time increase the effect of spark is more and due to which material removal rate is increase. WF, T off and WT are less significant parameter

6. Comparative Analysis of Soft and Hard Wire Electrode on WEDM Performance Parameters on The Basis of Experimental Results

The following results found after experimentation.

Table no 1.6: Comparative table of Soft and Hard wire electrode

PARAMETER	SOFT WIRE ELECTRODE	HARD WIRE ELECTRODE
Surface roughness	Soft wire electrode have higher surface roughness than hard wire electrode	Hard wire electrode have lower surface roughness than soft wire electrode
Cutting speed	Soft wire electrode have higher Cutting speed than hard wire electrode	Hard wire electrode have lower Cutting speed than soft wire electrode
Material removal rate	Soft wire electrode have higher material removal rate than hard wire electrode	Hard wire electrode have lower material removal rate than soft wire electrode

From Experimental results of soft and hard wire electrode it is concluded that the soft wire electrode have higher surface roughness, cutting speed and material removal rate than hard wire electrode.

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