OPTIMIZATION OF PROCESS PARAMETERS FOR WIRE EDM OF EN8 STEEL USING TAGUCHI AND TOPSIS THROUGH PYTHON PROGRAM

A project report submitted

in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

Submitted by

A. VAMSI KRISHNA	**318126520055**
S. ANIL KUMAR	**318126520052**
M. SRI VARSHINI	**318126520028**
B. PRANEETH BABU	**318126520009**
P. BALAKRISHNA	**319126520L15**

Under the guidance of

Dr. M. RAJA ROY, M.E., Ph. D

Associate Professor

Department of Mechanical Engineering

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

Autonomous status accorded by UGC and Andhra University (Approved By AICTE,

Permanently Affiliated to Andhra University &Accredited by NBA Tier-1 by NAAC)

Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (Dist.)- 531162

2022

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Affiliated to Andhra University)

Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

CERTIFICATE

This is to certify that the Project Report entitled "**OPTIMIZATION OF PROCESS PARAMETERS FOR WIRE EDM OF EN8 STEEL USING TAGUCHI AND TOPSIS THROUGH PYTHON PROGRAM**" has been carried out by A VAMSI KRISHNA (318126520055), S ANIL KUMAR (318126520052), M SRI VARSHINI (318126520028), B PRANEETH BABU (318126520009), P BALAKRISHNA (319126520L15), my guidance, in partial fulfilment of the requirements of Degree of "Bachelor of Engineering" in Mechanical Engineering of ANITS, Visakhapatnam.

APPROVED BY:

M Rajaroy   20.5.22

PROJECT GUIDE	**HEAD OF THE DEPARTMENT**
(Dr. M RAJA ROY)	**(Dr. B. NAGA RAJU)**
Associate Professor	**Head of the Department**
Dept. of Mechanical Engg.	**Dept. of Mechanical Engg.**
ANITS, Sangivalasa	**ANITS, Sangivalasa**
Visakhapatnam	**Visakhapatnam**

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A P

THIS PROJECT WORK IS APPROVED BY THE FOLLOWING BOARD OF EXAMINERS

INTERNAL EXAMINER.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A.P.

EXTERNAL EXAMINER.

ACKNOWLEDGEMENT

We are extremely fortunate to work under the guidance of **Dr.M RAJA ROY**, M.E., Ph. D, Associate Professor of Mechanical Engineering Department, Anil Neerukonda Institute of Technology and Science. He provided extraordinary guidance and support. His suggestions in the experimental stage, interpretation of results and these writings have been really great help.

We express our sincere thanks to **Prof. T.V. HANUMANTHA RAO**, M. Tech, MBA, Ph. D, Principal and **Prof. B. NAGARAJU** M. Tech, M.E, Ph.D., Head of Mechanical Department, Anil Neerukonda Institute of Technology and Science for their valuable suggestions, for completion of this project work.

Sincere regards to all other staff members who are helping us directly and indirectly in handling this project work progressively towards success.

A. VAMSI KRISHNA (318126520055)

S. ANIL KUMAR (318126520052)

M. SRI VARSHINI (318126520028)

B. PRANEETH BABU (318126520009)

P. BALAKRISHNA (319126520L15)

ABSTRACT

The Wire Cut EDM is a non-Conventional machining process where the metal is fabricated into desired shape by using electrical discharges (sparks). This research is to obtain the optimum process parameters to get minimum surface roughness and maximum metal removal rate in Wire Cut EDM simultaneously by multi response optimization using TOPSIS based Taguchi's method. Data is collected from Wire Cut EDM machine by different samples of experiments. The input of the model consists of Pulse on time, Pulse off time, Input power and Feed rate while the output of the model is Surface roughness and Metal removal rate. Design of experiments for conducting to measure surface roughness and metal removal rate was determined by Taguchi experimental design method. Orthogonal arrays of Taguchi, signal-to-noise ratio and analysis of variance are employed to find the optimum parameters to minimizing the surface roughness and metal removal rate using python program. Analysis has been done and results were predicted, and percentage of error has been calculated. Percentage of contribution for each parameter was obtained by Analysis of Variance.

Keywords: Taguchi, TOPSIS, ANOVA, Python, Wire EDM, optimization, material removal rate surface roughness.

List of Contents

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 Wire Cut EDM:

Electrical Discharge machining is a non-conventional thermoelectric process which erodes material from the work piece by a series of discrete sparks between a work and tool electrode immersed in a liquid di-electric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are ejected and floated away by the dielectric. The sparks occurring at high frequency continuously and effectively remove the work piece material by melting and evaporation. The dielectric acts as a de-ioninsing medium between the two electrodes and its flow evacuates the resolidified material debris from the gap assuring optimal conditions for spark generation. In wire EDM metal is cut with a special metal wire electrode that is programmed to travel along a programmed path. A wire EDM generates spark discharges between a small wire electrode (usually less than 0.5mm diameter) and a work piece with de-ioninsed water as the dielectric medium and erodes the work piece to produce complex two- or three-dimensional shapes according to a Numerical Controlled path.

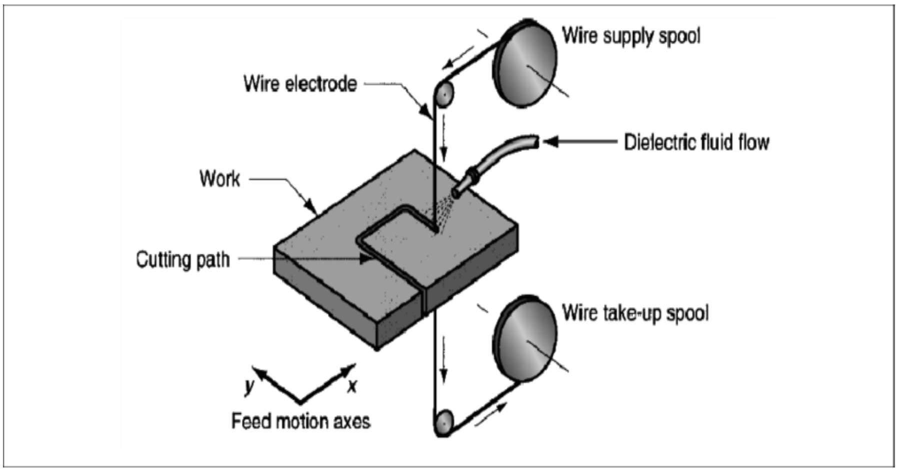

Fig 1.1 Wire EDM schematic diagram

The wire cut EDM uses a very thin wire 0.02 to 0.03 mm in diameter as an electrode and machines a work piece with electrical discharge like a band saw by moving either the work piece or wire erosion of the metal utilizing the phenomenon of spark discharge that is very same as in conventional EDM. The prominent feature of a moving wire is that a complicated cut out can be easily machined without using a forming electrode. Wire cut EDM machine basically consists of a machine proper composed of a work piece contour movement control unit (NC unit or copying unit), work piece mounting table and wire driven section for accurately moving the wire at constant tension, a machine power supply which applies electrical energy to the wire electrode and a unit which supplies a dielectric fluid with constant specific resistance.

1.1.1 Advantages of WEDM Process:

- As continuously travelling wire is used as the negative electrode, so electrode fabrication is not required as in EDM.
- There is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining.
- WEDM process can be applied to all electrically conducting metals and alloys irrespective of their melting points, hardness, toughness or brittleness.
- Users can run their work pieces over night or over the weekend unattended.

1.1.2 Disadvantages Of WEDM Process:

- High capital cost is required for WEDM process.
- There is a problem regarding the formation of recast layer.
- WEDM process exhibits very slow cutting rate.
- It is not applicable to very large work piece.

1.1.3 Applications Of Wire EDM:

Wire electrical discharge machining is mainly used to cut contour shapes and design into hard metals, which are otherwise difficult to machine. Contour parts can be easily cut with help of wire cut EDM.

- Tooling elements
- Automobile parts
- Plastic Moulding
- Dies, Hobs Blanking
- Shear Blades.
- Hot Shearing Tools
- Hardened Rolls.

- Thread Rolling Dies
- Blade Cutters for Wire Nails.
- Dies for Cold Nut Manufacturers Etc.

Fig 1.2 Various shapes cut with wire cut EDM

1.2 Process Parameters:

1.2.1 Pulse on Time:

It is the duration of time for which the current is allowed to flow in each cycle. It is denoted as T_{ON} and expressed in microseconds (µs). During WEDM all the work is done during pulse duration (On time). The erosion rates are affected mainly by pulse parameter. The spark gap is bridged, current is generated, and the work is accomplished. The longer the spark is sustained, the higher is the material removal. Consequently, the resulting craters will be broader and deeper therefore the surface finish will be rougher. Obviously with shorter duration of sparks the surface finish will be better.

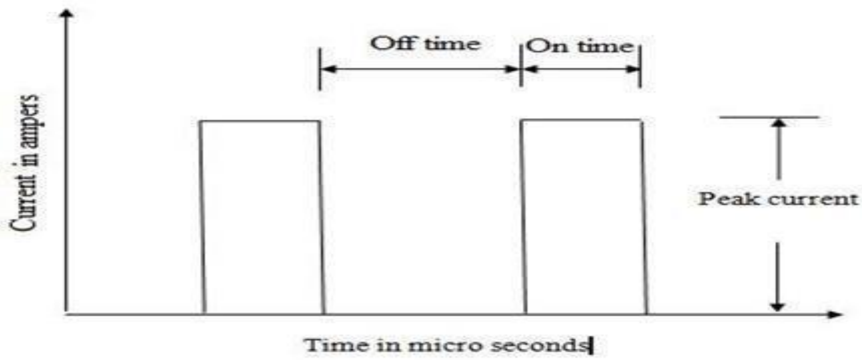

Fig 1.3 Series of electrical pulses at the inter electrode gap

1.2.2 Pulse off Time:

It is the duration of time between two simultaneous sparks. It is also called pulse interval. It is denoted as T_{OFF} and expressed in microseconds (μs). While most of the machining takes place during on time of the pulse, the off time during which the pulse rests and the re-ionization of the die-electric takes place, can affect the speed of the operation in a large way. Longer is the off time greater will be the machining time. But this is an integral part of the EDM process and must exist. The off time also governs the stability of the process. An insufficient off time can lead to erratic cycling and retraction of the advancing servo, slowing down the operation cycle. In addition, the interval time also provides the time to clear the disintegrated particles from the gap between the electrode and work piece for efficient cut removal. Too short pulse interval will increase the relative wear ratio and will increase the surface roughness of the machine surface.

1.2.3 Spark Gap:

It is the distance between the electrode and the workpiece during the EDM process.

1.2.4 Peak Current:

Peak current is the maximum value of the current passing through the electrodes for the given pulse. It is denoted by IP and expressed in amperes (A).

1.2.5 Spark Gap Voltage:

It gives the specific voltage for the actual gap between the work piece material and the wire. The spark gap voltage is also known as open circuit voltage. It is denoted by SV and expressed in volts (V).

1.2.6 Wire Feed:

The rate at which the wire electrode travels and continuously fed along the wire guide path for continuous sparking is called wire feed. Maximum wire feed is required in order to avoid wire breakage, to have better machining and better material removal rates

1.2.7 Wire Tension:

The amount of stretch in the wire between the upper and lower wire guides is called the wire tension and it is measured as gram equivalent load. In order to keep wire straight between two guides wire is kept continuously kept under tension. Wire tension is directly proportional to the thickness of the work piece, i.e., more the thickness of workpiece more the tension required. Improper setting of tension may result in the inaccuracies as well as wire breakage.

1.3 Response Parameters:

1.3.1 Surface Roughness:

Surface roughness, often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface metrology, roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.

1.3.2 Material Removal Rate:

Material removal rate (MRR) is the amount of material removed per time unit (usually per minute) when performing machining operations. The more material removed per minute, the higher the material removal rate. The MRR is a single number that enables you to do this. It is a direct indicator of how efficiently you are cutting, and how profitable you are. MRR is the volume of material removed per minute. The higher the cutting parameters the higher the MRR.

1.4 Minitab:

Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB 80, a statistical analysis program by NIST. Statistical analysis software such as Minitab automates calculations and the creation of graphs, allowing the user to focus more on the analysis of data and the interpretation of results. It is compatible with other Minitab, LLC software. Minitab is a software product that helps you to analyze the data. This is designed essentially for the Six Sigma professionals. It provides a simple, effective way to input the statistical data, manipulate that data, identify trends and patterns, and then extrapolate answers to the current issues. This is most widely used software for the business of all sizes - small, medium and large. Minitab provides a quick, effective solution for the level of analysis required in most of the Six Sigma projects. Minitab, originally intended as a tool for teaching statistics, is a general-purpose statistical software package designed for easy interactive use. Minitab is well suited for instructional applications but is also powerful enough to be used as a primary tool for analyzing research data.

1.4.1 Benefits Of Minitab:

The main benefits of Minitab are its user-friendliness, its Assistant feature, and its customer service.

Data analysis can be made more thorough with Minitab Statistical Software and its user-friendly tools, so much so that substantial data can be drawn even by people without advanced knowledge of statistics. Businesses benefit from it, and it can also be used to teach data analysis and statistics in universities and colleges.

Users are also aided in data analysis and result in interpretation by the Assistant feature. Armed with data on which areas can be improved, users can formulate better measures to upgrade process and product quality as well as to improve efficiency.

There are also several features that help user's meet their quality improvement goals as well as simplify workflows. Sharing, rolling out, and replicating a project is made easy by Project Roadmaps. Statistics can also be monitored in real time with Instant Insights, which automatically displays the data on the program's dashboard.

Further analysis of derived statistics can be made with Minitab Quality Trainer, which is the supplementary application that goes with the software. Users can utilize this as a cost-effective method of studying statistics when they are online. Users can also confidently present their data with Companion by Minitab.

1.5 TOPSIS:

TOPSIS stands for technique for order preference by similarity to ideal solution. This method was developed by Hwang and Yoon in the year 1995. Technique for order preference by similarity to ideal solution (TOPSIS) is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other side the farthest distance of the negative ideal solution. The ideal solution is a hypothetical solution for which all attribute values correspond to the minimum attribute values in the data base.

TOPSIS thus gives a solution that is not only closest to the hypothetically best but also farthest from the hypothetically worst.

1.6 TAGUCHI:

In any experiment, the results depend to a large degree on the way in which the data were collected. In a lot of cases, full factorial experiments are conducted or-one-factor-at-a-time strategies are followed. The former cannot be implemented when there are too many factors under consideration because the number of repetitions required would be prohibitive, from a time and cost viewpoint. The latter are not able to produce credible results in case interactions among the factors exist. The most efficient method of experimental planning is DoE, which was adopted in this paper. DoE incorporates the orthogonal arrays (OAs), developed by Taguchi, to successfully design and conduct fractional factorial experiments that can collect all the statistically significant data with the minimum possible number of repetitions.

DoE dictates a series of steps to follow for the experiment to yield an improved understanding of product or process performance. These steps involve:

(a) Stating the problem,

(ii) Stating the objectives of the experiment,

(iii) Selecting the quality characteristics and the measurement systems,

(iv) Selecting the factors that may influence the quality characteristics,

(v) Selecting levels for the factors,

(vi) Selecting the appropriate OA,

(vii) Selecting the interactions that may influence the quality characteristic,

(viii) Assigning factors to OAs and locating interactions,

(ix) Conducting the experiment repetitions as described by the OAs,

(x) Analyzing the experimental results,

(xi) Conducting a confirmation experiment.

What distinguishes DoE from other methodologies is steps vi–viii, which will be briefly described. There are three types of OAs, those that deal with two-level factors, those that deal with three-level factors and those that deal with mixed-level factors. The selection of the appropriate OA is based on the following criteria: the number of factors and interactions of interest, the number of levels for the factors of interest and the desired experimental resolution or cost limitations. The first two determine the smallest OA that it is possible to use, while the third gives the possibility to conduct a larger experiment with higher resolution. Resolution can vary from 1 (lowest) to 4 (highest) and it indicates the clarity with which each individual effect of factors and interactions may be evaluated in an experiment. In order to assign the various factors to an OAs column, the following mathematical property should be taken into account. If one factor is assigned to any particular column and a second factor to any other particular column, a specific third column will automatically have the interaction of those factors assigned to it. The pattern of which columns will be interaction columns is known for all of the OAs and it is visualized through the interaction tables and linear graphs. It must be noted that not all of the interactions between the factors are affecting the quality characteristic of interest. Consequently, the assigning of factors in an OA should be made so as for the interactions that is thought of as most influential to not be contained in the same column as a main factor that is for the experiment to have a higher resolution.

1.7 Analysis of variance (ANOVA)

It is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among group means in a sample. ANOVA was developed by statistician and evolutionary biologist Ronald Fisher. The ANOVA is based on the law of total variance, where the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether two or more population means are equal, and therefore generalizes the t-test beyond two means.

1.7.1 Study designs of ANOVA

There are several types of ANOVA. Many statisticians base ANOVA on the design of the experiment, especially on the protocol that specifies the random assignment of treatments to subjects; the protocol's description of the assignment mechanism should include a specification of the structure of the treatments and of any blocking. It is also common to apply ANOVA to observational data using an appropriate statistical model.

Some popular designs use the following types of ANOVA:

- One-way ANOVA is used to test for differences among two or more independent groups (means), e.g., different levels of urea application in a crop, or different levels of antibiotic action on several different bacterial species, or different levels of effect of some medicine on groups of patients. However, should these groups not be independent, and there is an order in the groups (such as mild, moderate and severe disease), or in the dose of a drug (such as 5 mg/mL, 10 mg/mL, 20 mg/mL) given to the same group of patients, then a linear trend estimation should be used. Typically, however, the one-way ANOVA is used to test for differences among at least three groups, since the two-group case can be covered by a t-test. When there are only two means to compare, the t-test and the ANOVA F-test are equivalent; the relation between ANOVA and t is given by $F = t2$
- Factorial ANOVA is used when the experimenter wants to study the interaction effects among the treatments.
- Repeated measures ANOVA is used when the same subjects are used for each treatment (e.g., in a longitudinal study).
- Multivariate analysis of variance (MANOVA) is used when there is more than one response variable.

CHAPTER 2

LITERATURE SURVEY

2 LITERATURE SURVEY

Literature review provides help for the present study. It works as helping hand to conduct the analysis. This chapter will play a part to get the information about wire cut electrical discharge machine and will give idea to operate the test and form the early stage of the projects; various literature studies have been done. Research journals, books, printed or online conference article were the main sources of guidance and used as a supporting material in the project. Literature review section works as reference, to give information and guidance based on journal and other source in the media. This chapter reports the literature survey related to the area of Wire Electrical Discharge Machine, process parameters, response parameters, Taguchi design of experiments, TOPSIS.

2.1 Sliding wear behavior of Ti6Al4v implant alloy in the simulated body environment:

M. Raja Roy et al. [1] studied the wear behavior of Titanium alloys which are widely used in medical applications due to their bio compatibility. Life of the implant material depends upon its wear resistance. Implants are generally placed inside the human body; Hence wear behavior was studied in the simulated body environment using Hank's solution. Wear tests were conducted using Pin on disc wear testing machine with ASTM G-99 standard specimens. In this study, the effect of load, speed and distance on the wear behavior were experimentally investigated.

Design of experiments for conducting to wear test was determined by Taguchi experimental design method. Orthogonal arrays of Taguchi, signal-to-noise ratio and analysis of variance are employed to find the optimum parameters to minimizing the wear using MINITAB-17 software. The results showed that load is the most important parameter influencing the wear. The predicted values and experimentally measured values are good in agreement and were confirmed by validating experiments.

2.2 Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade

M. Durairaj et al [2]. the study is made to optimize the process parameters during machining of Stainless Steel 304 by wire electrical discharge machining (WEDM) using

Grey relational theory and Taguchi optimization technique. The objective of optimization is to attain the minimum kerf width and the best surface quality simultaneously and separately. The input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. The optimal value is obtained for surface roughness and kerf width by using Taguchi optimization technique, optimized value is obtained separately. Additionally, the analysis of variance (ANOVA) is too useful to identify the most important factor.

2.3 Optimization of Wire EDM Process Parameters in Machining SS316 Using DEAR Method

Ch. Maheswara Rao, K. Venkata Subbaiah [3]. The present work is to explore the effect of Wire EDM process parameters on machining performance characteristics of SS316 material. A series of experiments were carried out based on L27 Orthogonal Array (OA) for the Wire EDM parameters of Pulse-on-Time (TON), Pulse off-Time (TOFF), Wire Feed (WF), Wire tension (WT) and Servo Voltage (SV) taken at three different levels. The response parameters of Material Removal Rate (MRR) and Roughness (Ra) were optimized using a hybrid Taguchi method coupled with Data Envelopment Analysis based Ranking (DEAR). From the results of computed Multi Performance Rank Index (MRPI) values the optimal combinations were obtained.

2.4 Multiple Optimization of Wire EDM Machining Parameters Using Grey Based Taguchi Method for Material HCHCR

Anwarul Haque et al [4]. This paper investigated the optimal set of process parameter such as Ton, Toff, Wp, Wf in wire EDM machining process to find out the variation in two output parameter such as material removal rate (MRR), and surface roughness (Ra) on material high chromium high carbon steel (HCHCr) using wire Brass/super alloy (coated). Experimentation was conducted on orthogonal array L-9 based on DOE. Analysis of experiment has been carried out using GRA. All the experimental data are fed into Minitab software, through which various tables, graphs & optimum values were obtained. The experimental result reveals that the optimum setting of input parameters significantly improves Wire EDM process.

2.5 Optimization of Material Removal Rate and Surface Roughness of MoS2 Reinforced Aluminum Metal Matrix Composite in Wire EDM Process

Dr M Raja Roy et al [5] tried to study the effect of Wire Electric Discharge Machining (WEDM) parameters like pulse-on time, pulse-off time, peak current and % MoS2 on Surface Roughness (Ra) and Material Removal Rate (MRR) in Aluminum Metal Matrix Composites (AMMCs). The composite material containing aluminum alloy 6082 as matrix, Molybdenum disulphide as reinforcement was produced by Stir casting technique with different weight percentages (0%, 2%, 4%). Experimentation was conducted in a series of tests called runs, in which changes were made in the input variables in order to identify the reasons for changes in the output response using Taguchi design. The results showed that maximum material removal rate is obtained at 2% MoS2 and minimum surface roughness is obtained at 4% MoS2.

2.6 Optimization of process parameters for WEDM of Inconel 825 using Grey Relational Analysis using Grey Relational Analysis:

G. Rajyalakshmi et al [6]. presented experiments with eight process parameters: pulse on time, pulse off time, corner servo voltage, wire feed, wire tension, dielectric flow rate, spark gap voltage and servo feed were varied in three different levels. Data related to the process response is SR which corresponds to randomly chosen different combinations of factor setting. These data have been utilized to fit a mathematical model for each of the responses, which can be represented as a function of the eight process parameters. Predicted data given by the models as per Taguchi's L18 Orthogonal Array (OA) design have been used in search of an optimal parametric combination to achieve desired minimum roughness value. Inconel825 is used as work piece material. Pulse on time and wire feed rate have been most significant effect on SR.

2.7 Optimization of Wire EDM Process parameters in Machining SS316 using DEAR method.

R Ramesh Babu [7] The work explored the effect of Wire EDM process parameters on machining performance characteristics of SS316 material. A series of experiments were carried out based on L27 Orthogonal Array (OA) for the Wire EDM parameters of Pulse-on-Time (TON), Pulse off-Time (TOFF), Wire Feed (WF), Wire tension (WT) and Servo Voltage (SV) taken at three different levels. The response parameters of Material Removal Rate (MRR) and Roughness (Ra) were optimized using a hybrid Taguchi method coupled with Data Envelopment Analysis based Ranking (DEAR). From the results of computed Multi Performance Rank Index (MRPI) values the optimal combinations were obtained. ANOVA results showed that Pulse-off-Time (TOFF) and Servo Voltage (SV) have the highest influence on multi-response.

2.8 Experimental Investigation on Optimization of the Controlling Factors for Machining Al 6061/MoS2 Metal Matrix Composites with Wire EDM

M. Geeta Rani [8] investigated the effect of Wire electrical discharge machining (WEDM) parameters such as pulse-on time (T On), pulse-off time (TOff), peak current (Ip) and wire feed (Wf) on material removal rate (MRR) and surface roughness (Ra) in metal matrix composites (MMCs) consisting of Aluminum alloy (Al6061) and MoS2 is discussed. The Al6061 material is reinforced with MoS2 powder of 2-micron particle size with 4% weight ratio. The experiments were carried out based on design of experiments approach using L9 orthogonal array using CNC SPRINTCUT WEDM. The results were analyzed and optimized using analysis of variance and response graphs.

2.9 Optimization of Machining Parameters for AISI 316L and 317L Austenitic Stainless Steels using ECO-CUT WIRE EDM Technique

M.V.N Srujan Manohar et al [9]. The paper investigates the optimization of machining parameters during machining of AISI 316L and 317L by eco-cut wire electrical discharge machining (WEDM) using Response surface methodology(RSM) and Analysis of variance(ANOVA).The input machining parameters for both 316L and 317L stainless steel materials are pulse-on time(Ton),pulse-off time(Toff),voltage(V) and wire tension(WT).The response parameters in this process are material removal rate(MRR),surface roughness(Ra) and cutting speed(CS).Initially both the metals are machined on Wire EDM. After that Response surface methodology Box Behnken Design Method has been used in present work to optimize the WEDN performance measures like MRR, Ra and CS. After optimization, ANOVA has been used to know the significant parameters and their contribution.

2.10 Optimization of WEDM Process Parameters on Titanium Alloy Using Taguchi Method

Lokeswara Rao T et al [10] This paper investigates the optimum cutting parameters for Titanium Grade5 (Ti-6Al-4V) using Wire-cut Electrical Machining Process (WEDM). The response of Volume Material Removal Rate (MRR) and Surface Roughness (Ra) were considered for improving the machining efficiency. A brass wire of 0.25mm diameter was applied as tool electrode to cut the specimen. The Experimentation has been done by using Taguchi's L25 orthogonal array (OA) under different conditions like pulse on, pulse off, peak current, wire tension, servo voltage and servo feed settings. Regression equation is developed for the VMRR and Ra. The optimum parameters are obtained by using Taguchi method.

2.11 Optimization of process parameters for WEDM of Inconel 825 using grey relational analysis.

Pawan Kumar et al [11]. the study is made to optimize the process parameters during machining of Inconel825 by wire electric discharge machining (WEDM) using Grey Relational Analysis. The objective of the optimization is to satisfy the production and quality requirements with improved precision and accuracy. The input parameters selected for optimization are pulse-on time (Ton),pulse-off time(Toff),peak current(IP),gap voltage(SV),wire feed rate(WF) and wire tension(WT).The response parameters which are optimized are material removal rate(MRR),wire wear ratio(WWR) and surface roughness(SR).In this study since the process is with multi performance characteristics, therefore optimization of WEDM parameters has been done by employing Response Surface Methodology (RSM)in combination with GRA using Inconel825 as work material. The multi response optimization resulted in 13.62% improvement in MRR.SR and WWR were reduced by 13.97% and 4.03% respectively Thus, the optimum parametric combination obtained from the present study will be advantageous for working on high strength, high thermal conductivity and low melting point materials like nickel alloys.

2.12 Optimization of Process Parameter of Wire Electrical Discharge Machine by Response Surface Methodology on Inconel-600:

C.D. Shah et al [12] the study is made to optimize the process parameters during machining of Inconnel-600 by wire electrical discharge machining (WEDM) using response surface methodology (RSM). Four input process parameters of WEDM namely Peak Current, Pulse-On time, Pulse-Off time and Wire Feed rate were chosen as variables to study the process performance in terms of Material Removal Rate. In that work, the parametric optimization method using Taguchi's robust design is proposed for wire-cut electric discharge machining of Inconel-600. So, experimentation has been done by using Taguchi's Mixed L18 (21×33) orthogonal array. Each experiment was conducted under different conditions of pulse on time, pulse off time, peak current, and wire feed rate. The response of material removal rate is considered for improving the machining efficiency. Optimal combinations of parameters were obtained by this method. The level of importance of the machining parameters on the material removal rate is determined by using ANOVA and it is shown that Pulse on, pulse off, Peak current are most significant. And also conclude that the cutting rate increases with the increase of pulse on time and peak current and decreases with increase in pulse off time.

2.13 Effect of Process Parameters on Metal Removal Rate in Wire Electrical Discharge Machining of En31 Steel

S Sivakiran et al [13] evaluated the influence of various machining parameters Pulse on, Pulse off, Bed speed and Current on metal removal Rate (MRR). The relationship between control parameters and Output parameter (MRR) is developed by means of linear regression. Taguchi's L16 (4*4) Orthogonal Array (OA) /designs have been used on EN-31 tool steel to achieve maximum metal removal rate. The results obtained were analyzed using S/N Ratios, Response table and Response Graphs with the help of Minitab software. The better Parameter setting is Pulse on 24 μsec, pulse off 6 μsec, Bed speed 35 μm/s and Current to obtain maximum metal removal rate.

2.14 Simultaneous optimization of material removal rate and surface roughness for WEDM of WCCo composite using grey relational analysis along with Taguchi method

Kamal Jangra et al [14]. In this paper, wire electrical discharge machining of WC-Co composite is studied. Influence of taper angle, peak current, pulse-on time, pulse-off time, wire tension and dielectric flow rate are investigated for material removal rate (MRR) and surface roughness (SR) during intricate machining of a carbide block. In order to optimize MRR and SR simultaneously, grey relational analysis (GRA) is employed along with Taguchi method. Through GRA, grey relational grade is used as a performance index to determine the optimal setting of process parameters for multiple machining characteristics. Analysis of variance (ANOVA) shows that the taper angle and pulse-on time are the most significant parameters affecting the multiple machining characteristics.

2.15 Comparison between Taguchi Method and Response Surface Methodology (RSM) In Optimizing Machining Condition

Mohd Sazali Md Said et al [15] experimented on different kind of statistical optimization techniques which are available for optimizing the different parameters in machining and compared the results. The experiments were carried out such that the resulting optimized parameters will lead to a compromise between the productivity and the surface quality.

2.16 Optimization OF Multiple-Machining Characteristics in Wire EDM OF Punching DIE using GREY RELATIONAL Analysis

Kamal Jangra et al [16]. The study is made to optimize the multiple machining characteristics during machining of punching die by Wire EDM using GRA and Taguchi Method. The process parameters which were investigated using mixed L18 orthogonal array are peak current (IP), pulse-on time (Ton), pulse-off time (Toff), wire speed (WS) and wire tension (WT). The performance characteristics which are optimized in this study are cutting speed (CS), surface roughness (SR), and dimensional lag (Dlag). In order to optimize three machining characteristics GRA was utilized which were investigated during rough cutting operation in D3 tool steel. After selecting process parameters and their ranges, experimental results were obtained using Taguchi's design of experiment method. The results obtained after experimentation were cutting speed(3.80mm/min) with a dimensional lag of 0.008mm. But surface roughness was poor and can be improved by assigning high weightage in grey relational grade.

CHAPTER 3

DESIGN OF EXPERIMENTS

3 DESIGN OF EXPERIMENTS

In this chapter we deal with selection of materials, selection of process parameter, selection of levels and design of experiments by Taguchi method in Minitab software.

3.1 Selection of Material:

By studying various projects on CNC Wire EDM and keeping cost in mind we selected EN-8 Steel as work piece material.

3.1.1 EN-8 Steel:

EN8 also known as 080M40, is selected as the work piece material.EN8 is an unalloyed medium carbon steel grade with reasonable tensile strength. EN8 has good tensile strength and is often used in applications such as: shafts, gears, stressed pins, studs, bolts, keys etc.

Table 3.1 Chemical Composition of En8 Steel

C	Si	Mn	S	P
0.36-0.44	0.10-0.40	0.60-1.00	0.005(max)	0.05(max)

3.2 Selection of process parameter (Factors):

After care study of literature review, we selected pulse on time, pulse off time, wire feed and peak current as process parameters. Because these have great influence on output responses like metal removal rate and surface roughness.

3.3 Selection of levels:

We are selecting a four-level design by observing the parameters taken in various projects and keeping cost in mind. The levels of factors are designed as shown in Table 3.2.

Table 3.2Process parameters and levels

FACTORS	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Pulse ON Time(µs)	110	115	120	125
Pulse OFF Time(µs)	45	50	55	60
Peak Current(A)	200	210	220	230
Wire Feed(m/min)	2	3	4	5

3.4 Introduction to Design of Experiments (DOE)

Design of experiments (DOE) is defined as a branch of applied statistics that deals with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. DOE is a powerful data collection and analysis tool that can be used in a variety of experimental situations.

It allows for multiple input factors to be manipulated, determining their effect on a desired output (response). By manipulating multiple inputs at the same time, DOE can identify important interactions that may be missed when experimenting with one factor at a time. All possible combinations can be investigated (full factorial) or only a portion of the possible combinations (fractional factorial).

A strategically planned and executed experiment may provide a great deal of information about the effect on a response variable due to one or more factors. Many
experiments involve holding certain factors constant and altering the levels of another variable. This "one factor at a time" (OFAT) approach to process knowledge is, however, inefficient when compared with changing factor levels simultaneously. Many of the current statistical approaches to designed experiments originate from the work of R. A. Fisher in the early part of the 20th century. Fisher demonstrated how taking the time to seriously consider the design and execution of an experiment before trying it helped avoid frequently encountered problems in analysis. Key concepts in creating a designed experiment include blocking, randomization, and replication.

3.4.1 Blocking

When randomizing a factor is impossible or too costly, blocking lets you restrict randomization by carrying out all of the trials with one setting of the factor and then all the trials with the other setting.

3.4.2 Randomization

Refers to the order in which the trials of an experiment are performed. A randomized sequence helps eliminate effects of unknown or uncontrolled variables.

3.4.3 Replication

Repetition of a complete experimental treatment, including the setup.

A well performed experiment may provide answers to questions such as:

- What are the key factors in a process?
- At what settings would the process deliver acceptable performance?
- What is the key, main, and interaction effects in the process?
- What settings would bring about less variation in the output?

A repetitive approach to gaining knowledge is encouraged, typically involving these consecutive steps:

- A screening design that narrows the field of variables under assessment.
- A "full factorial" design that studies the response of every combination of factors and factor levels, and an attempt to zone in on a region of values where the process is close to optimization.
- A response surface designed to model the response.

3.5 Advantages of DOE

With real engineering examples, Czitromlisted the following advantages of DOE:

- A good amount of data can be obtained with lesser resources (experiments, time, material, etc.).
- The estimates of the effect of each factor (variable) on the response are more precise.
- It is a systematic way to estimate the interactions between the process factors.
- There is experimental information in a larger region of the factor space.

3.6 DOE Techniques

A survey was carried out within the industry which identifies the needs of using an efficient and practical technique for the experimentation. It was surveyed that 76% of industries consider themselves in need of a methodology. So here are listing some of the techniques that are in use in Industries. The list of the techniques considered is far from being complete since the aim of the section is just to introduce the reader into the topic showing the main techniques which are used in practice.

- Randomized complete block design
- Latin square
- Full factorial
- Fractional factorial
- Central composite
- Box-Behnken
- Plackett-Burman
- Taguchi
- Random
- Halton, Faure and Sobol sequences
- Latin hypercube
- Optimal design
- Response surface design

Several DOE techniques are available to the experimental designer. However, as it always happens in optimization, there is no best choice. The correct DOE technique selection depends on the problem to be investigated and on the aim of the experimentation.

3.7 Design of experiments by Taguchi method

As a researcher in Electronic Control Laboratory in Japan, Dr. Genechi Taguchi carried out significant research with DOE techniques in the late 1940's. He spent considerable effort to make this experimental technique more user-friendly (easy to apply) and applied it to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi method or Taguchi approach, was introduced in the USA in the early 1980's. Today it is one of the most effective quality building tools used by engineers in all types of manufacturing activities. The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations. DOE can be highly effective when you wish to: - Optimize product and process designs, study the effects of multiple factors (i.e., variables, parameters, ingredients, etc.) on the performance, and solve production problems by objectively laying out the investigative experiments. (Overall application goals). - Study Influence of individual factors on the performance and determine which factor has more influence, which ones have less. You can also find out which factor should have tighter tolerance and which tolerance should be relaxed. The information from the experiment will tell you how to allocate quality assurance resources based on the objective data. It will indicate whether a supplier's part causes problems or not (ANOVA data), and how to combine different factors in their proper settings to get the best results.

3.8 Advantage of DOE Using Taguchi Approach

The application of DOE requires careful planning, prudent layout of the experiment, and expert analysis of results. Based on years of research and applications Dr. Genechi Taguchi has standardized the methods for each of these DOE application steps described below. Thus, DOE using the Taguchi approach has become a much more attractive tool to practicing engineers and scientists.

- **Experiment planning and problem formulation**

Experiment planning guidelines are consistent with modern work disciplines of working as teams. Consensus decisions about experimental objectives and factors make the projects more successful.

- **Experiment layout**

High emphasis is put on cost and size of experiments... Size of the experiment for a given number of factors and levels is standardized... Approach and priority for column assignments are established... Clear guidelines are available to deal with factors and interactions (interaction tables)... Uncontrollable factors are formally treated to reduce variation... Discrete prescriptions for setting up test conditions under uncontrollable factors are described... Guidelines for carrying out the experiments and number of samples to be tested are defined.

- **Data analysis**

Steps for analysis are standardized (main effect, NOVA and Optimum) Standard practice for determination of the optimum is recommended... Guidelines for test of significance and pooling are defined.

- **Interpretation of results**

Clear guidelines about meaning of error term... Discrete indicator about confirmation of results (Confidence interval) ... Ability to quantify improvements in terms of dollars

- **Overall advantage**

DOE using Taguchi approach attempts to improve quality which is defined as the consistency of performance. Consistency is achieved when variation is
reduced. This can be done by moving the mean performance to the target as
well as by reducing variations around the target. The prime motivation behind the Taguchi experiment design technique is to achieve reduced variation (also known as ROBUST DESIGN). This technique, therefore, is focused to attain the desired quality objectives in all steps. The classical DOE does not specifically address quality. "The primary problem addressed in classical statistical experiment design is to model the response of a product or process as a function of many factors called model factors. Factors, called nuisance factors, which are not included in the model, can also influence the response... The primary problem addressed in Robust Design is how to reduce the variance of a product's function in the customer's environment." - MadhavPhadke, Quality Engineering using Robust Design.

3.9 Selection of Orthogonal array

A major step in the DOE process is the selection of orthogonal array based on number of factors and number of levels for each factor. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. The degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In present work three factors and four level were considered. Therefore, degrees of freedom were calculated as shown below.

1. Number of factors =4

2. Numbers of levels = 4

3. Degrees of freedom of each factor = 4-1=3

Based on the required minimum number of experiments the nearest orthogonal array Fulfilling the condition is L16.

3.10 DOE using Taguchi's method in Minitab:

1. Open new Minitab page

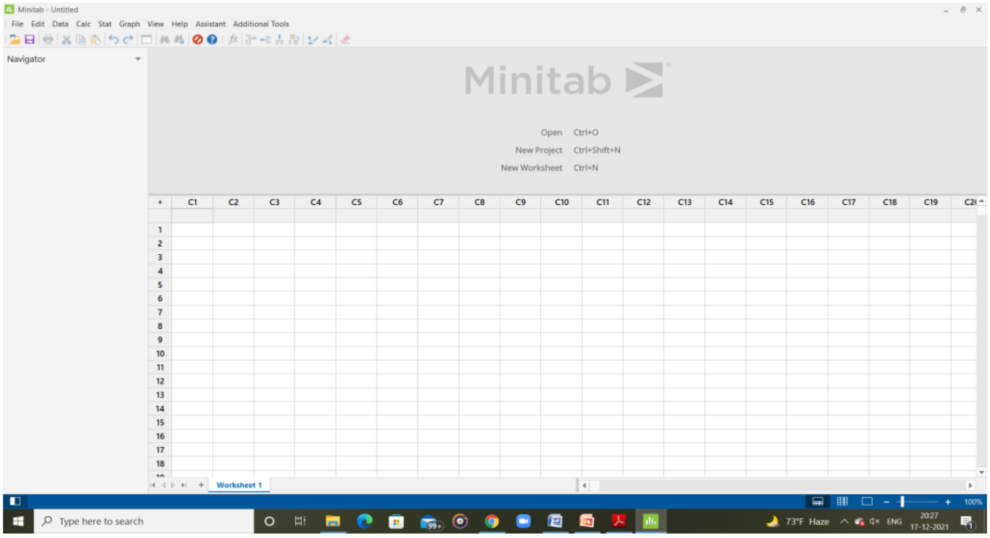

Fig 3.1 Minitab New Page

2. Selecting Taguchi DOE

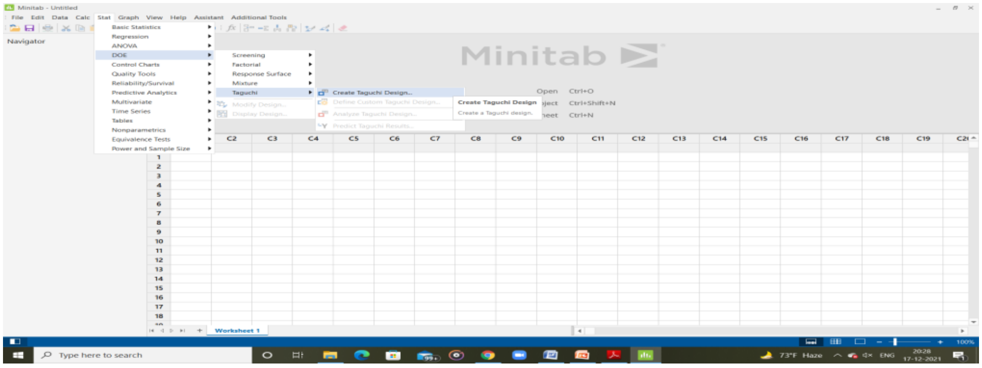

Fig 3.2 Selection of Taguchi Design

3. Giving the no of factors and levels

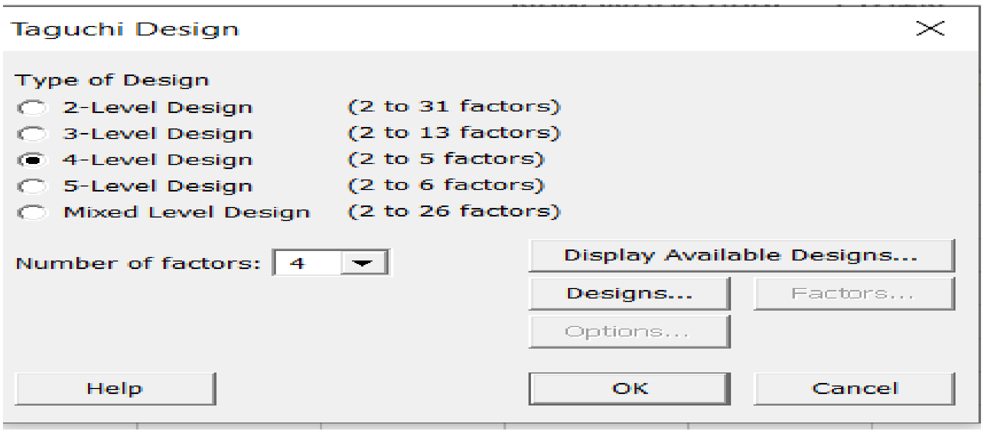

Fig 3.3Taguchi Factors and levels

4. Taguchi design: Available Design

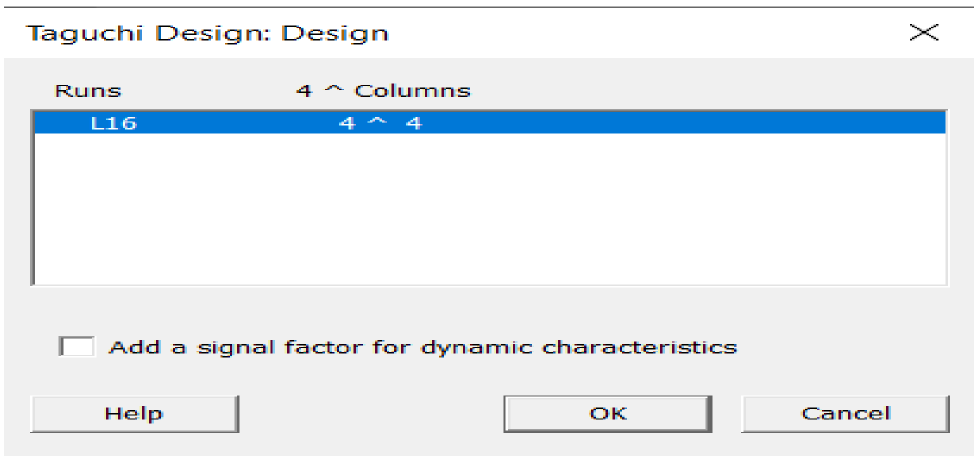

Fig 3.4 Taguchi available designs

5. Decide type of design

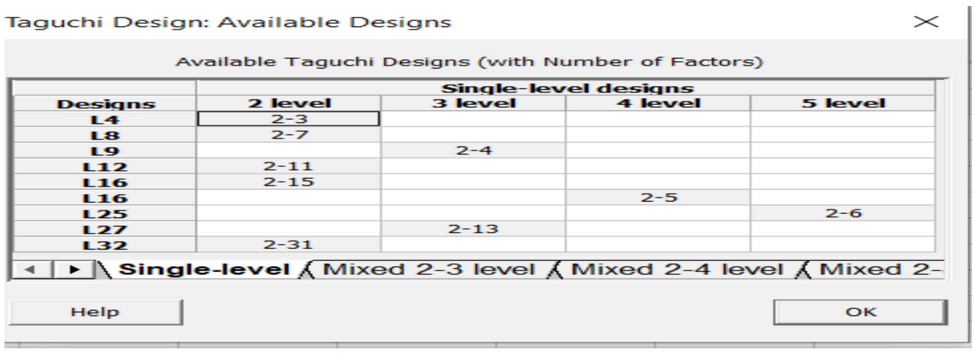

Fig 3.5 Deciding type of design

6. Taguchi Design: Factors

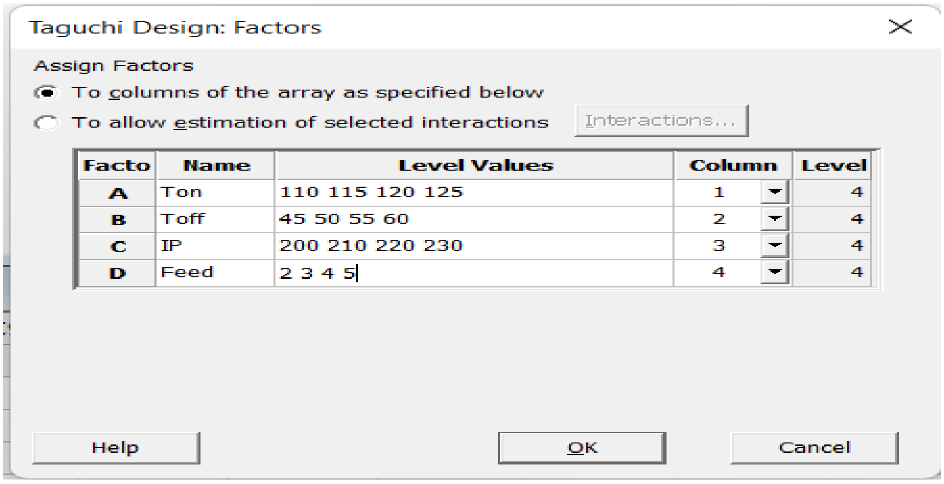

Fig 3.6 Taguchi Factors

7. After giving the factors and levels and click ok, then taguchi DOE appears as shown in fig below

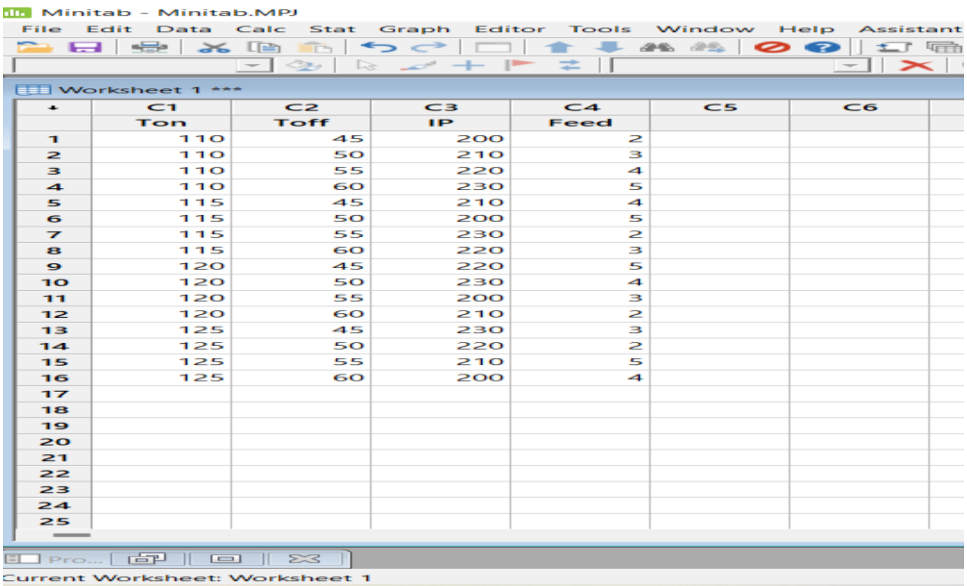

Fig 3.7 Taguchi DOE

After getting the DOE experiments should be done as per above 16 combinations.

CHAPTER 4

EXPERIMENTAL SETUP AND MACHINING

4 EXPERIMENTAL SETUP AND MACHINING

The experimental work was done by Taguchi design of experiments. Machining is done on EN8 work piece by CNC Wire Electrical Discharge Machining as per the DOE table as shown table 4.1. Metal removal rate and surface roughness are measured during the experiments. Analysis of results was done using TOPSIS and ANOVA.

Table 4.1 DOE Table

Expt	T_{on}(µs)	T_{off}(µs)	IP(A)	FEED (m/min)
1	110	45	200	2
2	110	50	210	3
3	110	55	220	4
4	110	60	230	5
5	115	45	210	4
6	115	50	200	5
7	115	55	230	2
8	115	60	220	3
9	120	45	220	5
10	120	50	230	4
11	120	55	200	3
12	120	60	210	2
13	125	45	230	3
14	125	50	220	2
15	125	55	210	5
16	125	60	200	4

4.1 Machining using CNC Wire EDM machine

The experimental setup and the experiment are designed and carried out at Machine shop. The primary goal of the dissertation work is to predict the MRR, surface roughness. The work is carried out in Electronica Sprint cut 734 Wire EDM machine 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.

Fig 4.1 Electronica Sprint cut 734 wire EDM Machine

4.1.1 Machining of work piece

The machining of work piece on CNC milling machine to make slots using the following procedure

- Clamping the work piece
- Locating the reference points
- Loading the program into cnc machine
- Running the program

Table 4.2 Constant parameters while machining

Peak Voltage (VP)	Flushing Pressure (WP)	Wire Tension (WT)	Spark gap Voltage (SV)	Servo Feed rate (SF)
2V	1 Kg/cm^2	8N	20V	2100 mm/min

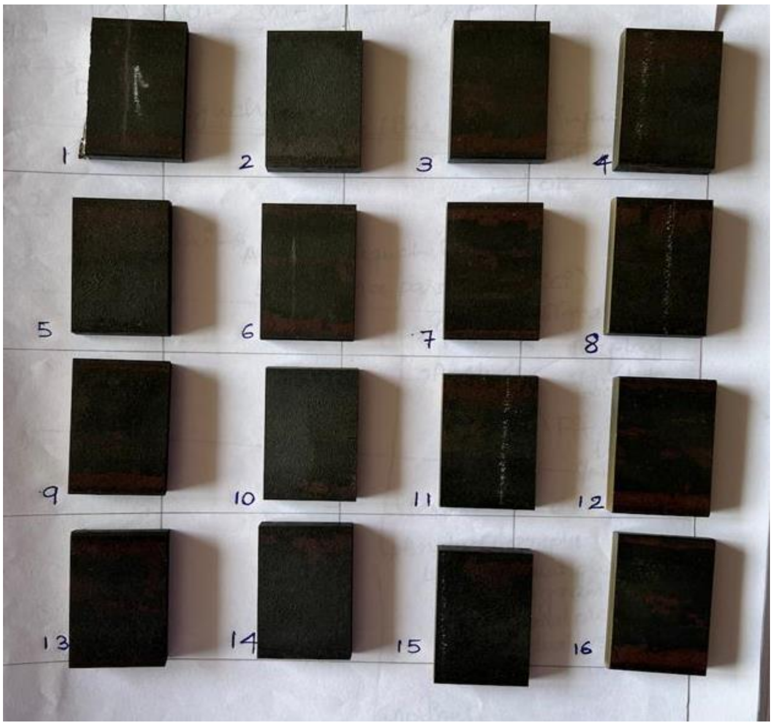

Fig 4.2Work pieces after machining

4.2 Measurement of Surface Roughness

Surface roughness is measured using the Surftest SJ-210- Series 178-Portable Surface Roughness Tester.

Features

- The 2.4-inch color graphic LCD provides excellent readability and an intuitive display that is easy to negotiate. The LCD also includes a backlight for improved visibility in dark environments.
- The Surftest SJ-210 can be operated easily using the buttons on the front of the unit and under the sliding cover.
- Up to 10 measurement conditions and one measured profile can be stored in the internal memory.
- An optional memory card can be used as an extended memory to store large quantities of measured profiles and conditions.
- Access to each feature can be password-protected, which prevents unintended operations and allows you to protect your settings.
- The display interface supports 16 languages, which can be freely switched.

- An alarm warns you when the cumulative measurement distance exceeds a preset limit.
- The Surftest SJ-210 complies with the following standards: JIS (JIS-B0601-2001, JIS-B0601-1994, JIS B0601-1982), VDA, ISO- 1997, and ANSI.
- In addition to calculation results, the Surftest SJ-210 can display sectional calculation results and assessed profiles, load curves, and amplitude distribution curves.

Fig 4.3 Surftest SJ-210- Series 178 Portable Surface Roughness Tester.

4.3 Measurement of Metal removal rate

Metal Removal Rate, is the measurement for how much material is removed from a part in a given period of time. Metal removal rate is measured using the formula [9]

$$MRR = \frac{WLT}{Time(in\ min)}$$

Where

L is length of workpiece =32mm

T is thickness of workpiece =6mm

W is width of cut = 0.27mm

Table 4.3Measured MRR and Ra

Expt	T_{on}(µs)	T_{off}(µs)	IP	FEED	MRR mm^3/min	Ra (µm)
1	110	45	200	2	3.585536	3.672
2	110	50	210	3	3.257184	3.398
3	110	55	220	4	3.262109	3.423
4	110	60	230	5	3.043627	3.65
5	115	45	210	4	4.424467	3.812
6	115	50	200	5	4.114286	3.552
7	115	55	230	2	3.646424	3.86
8	115	60	220	3	4.443429	3.628
9	120	45	220	5	6.2208	3.598
10	120	50	230	4	5.960766	3.845
11	120	55	200	3	4.443429	3.523
12	120	60	210	2	3.62208	3.618
13	125	45	230	3	9.82	3.447
14	125	50	220	2	5.265574	3.098
15	125	55	210	5	5.201338	3.323
16	125	60	200	4	7.886857	3.324

4.4 TOPSIS Method

TOPSIS- Techniques for order preferences by similarity to ideal solution. TOPSIS method has been applied to over the multi-response into single response. The steps followed for the TOPSIS in the present research work are given below.

Step 1 Decision matrix is normalized by using the following equation:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} \quad a_{ij}{}^2}}$$

Where i = 1··· m and j = 1 ···n.

a_{ij} represents the actual value of the th value of th experimental run and represents the corresponding normalized value.

Step 2 Equal weightage of 0.5 has been given.

Step 3 The weighted normalized decision matrix is then calculated by multiplying the normalized decision matrix by its associated weights. The weighted normalized decision matrix is formed as

$$V_{ij} = W_{ij} \times r_{ij}$$

Where i = 1 ··· m and j = 1 ···n represents the weight of the th attribute or criteria.

Step 4 Positive ideal solution (PIS) and negative ideal solution (NIS) are determined as follows:

$V^+ = (V_1^+, V_2^+, \dots \dots., V_n^+)$ maximum values
$V^- = (V_1^-, V_2^-, \dots . \dots, V_n^-)$ minimum values

Step 5 The separation of each alternative from positive ideal solution (PIS) and negative ideal solution (NIS) is calculated as

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \quad (V_{ij} - V_j^+)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \quad (V_{ij} - V_j^-)^2}$$

Where i = 1, 2, ...m

Step 6 The closeness coefficient of each alternative (CC_i) is calculated as

From the above procedure we can convert the multiple responses (MRR & Ra) to single response (CC_i).

$$CC_i = \frac{S_i^-}{S_i^{\mp} + S_i^-}$$

4.5 Calculation of S/N ratio (Taguchi Method)

4.5.1 Larger is the better

The signal to noise (S/N) ratio is calculated for each factor level combination. The formula for the larger is the better S/N ratio base 10 log is:

S/N = -10*log(S(1/Y2)/n)

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

4.5.2 Smaller is the better

The signal to noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller is the better S/N ratio base 10 log is:

S/N = -10*log(S(Y2)/n)

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

CHAPTER 5

PYTHON PROGRAMMING

5 PYTHON PROGRAMMING

Python is a high-level, interpreted, general-purpose programming language. Its design philosophy emphasizes code readability with the use of significant indentation. Python is a multi-paradigm programming language. Object-oriented programming and structured programming are fully supported, and many of its features support functional programming and aspect-oriented programming . Many other paradigms are supported via extensions, including design by contract and logic programming.

Python uses dynamic typing, and a combination of reference counting and a cycle-detecting garbage collector for memory management. It uses dynamic name resolution (late binding), which binds method and variable names during program execution.

5.1 Python uses in Mechanical Engineering

- Python is widely used to automate creation of CAD drawings
- It is widely used in conducting numerical analysis, the most popular application in mechanical engineering.
- Python is also used in other areas such as vibrations and dynamic motion, simulation and modeling engineering etc.

5.2 Python Libraries

A Python library is a reusable chunk of code that you may want to include in your programs/ projects. Compared to languages like C++ or C, a Python library do not pertain to any specific context in Python. Here, a 'library' loosely describes a collection of core modules. Essentially, then, a library is a collection of modules. A package is a library that can be installed using a package manager like rubygems or npm. The python libraries used in this python program are:

Openpyxl library, Math library, Matplot library

5.2.1 Matplot Library

Matplotlib is one of the most popular Python packages used for data visualization. It is a cross-platform library for making 2D plots from data in arrays. It provides an object-oriented API that helps in embedding plots in applications using Python GUI toolkits such as PyQt, WxPythonotTkinter. It can be used in Python and IPython shells, Jupyter notebook and web application servers also.

Matplotlib is written in Python and makes use of NumPy, the numerical mathematics extension of Python. It provides an object-oriented API that helps in embedding plots in applications using Python GUI toolkits such as PyQt, WxPythonotTkinter. It can be used in Python and IPython shells, Jupyter notebook and web application servers also.

Matplotlib has a procedural interface named the Pylab, which is designed to resemble MATLAB, a proprietary programming language developed by MathWorks. Matplotlib along with NumPy can be considered as the open-source equivalent of MATLAB.

Matplotlib was originally written by John D. Hunter in 2003. The current stable version is 2.2.0 released in January 2018.

To install openpyxl library we need to run the following command in command prompt.

pip install matplotlib

Functions used from matplotlib in the code
plot: Plot y versus x as lines and/or markers.
xlabel: Set the label for the x-axis.
ylabel: Set the label for the y-axis.
xticks: Get or set the current tick locations and labels of the x-axis.
show: Display a figure.

5.2.2 Openpyxl library

Openpyxl is a Python library for reading and writing Excel (with extension xlsx/xlsm/xltx/xltm) files. The openpyxl module allows Python program to read and modify Excel files.
For example, users might have to go through thousands of rows and pick out a few handfuls of information to make small changes based on some criteria. Using Openpyxl module, these tasks can be done very efficiently and easily. To install openpyxl library we need to run the following command in command prompt.

pip install openpyxl

5.3 Python code working for TOPSIS and Taguchi

STEP 1: Openpyxl,Matplot and Math libraries are imported in python

STEP 2: The Excel sheet is imported using the load workbook function

STEP 3: TOPSIS calculations is started by taking two variables mrr. and ra. which are of listed data type

STEP 4: The values of Material removal rate and Surface roughness from excel sheet are mapped into the variables mrr. and ra. respectively.

STEP 5: The TOPSIS calculations are done for the imported Material removal rate and Surface roughness values by giving equal weightages.

STEP 6: The Closeness co-efficient (CC_i) values are obtained using TOPSIS method and the TOPSIS calculations ends here.

STEP 7: The obtained Closeness co-efficient (CC_i) values are uploaded into the excel sheet automatically.

STEP 8: The Taguchi calculations starts here. Variables for four input parameters are created as dictionary data type and the values in each parameter are taken as key.

STEP 9: Experimental S/N ratio values are calculated for each combination of the orthogonal array.

STEP 10: The S/N ratio values are obtained for each parameter value using Taguchi calculations.

STEP 11: The graphs between the input parameter and S/N ratio are obtained using Matplot library.

STEP 12: The optimum values are obtained by considering the larger S/N ratio values as best.

STEP 13: Predicted S/N ratio values are calculated for each combination of the orthogonal array.

STEP 14: The calculations for confirmation test are done similarly

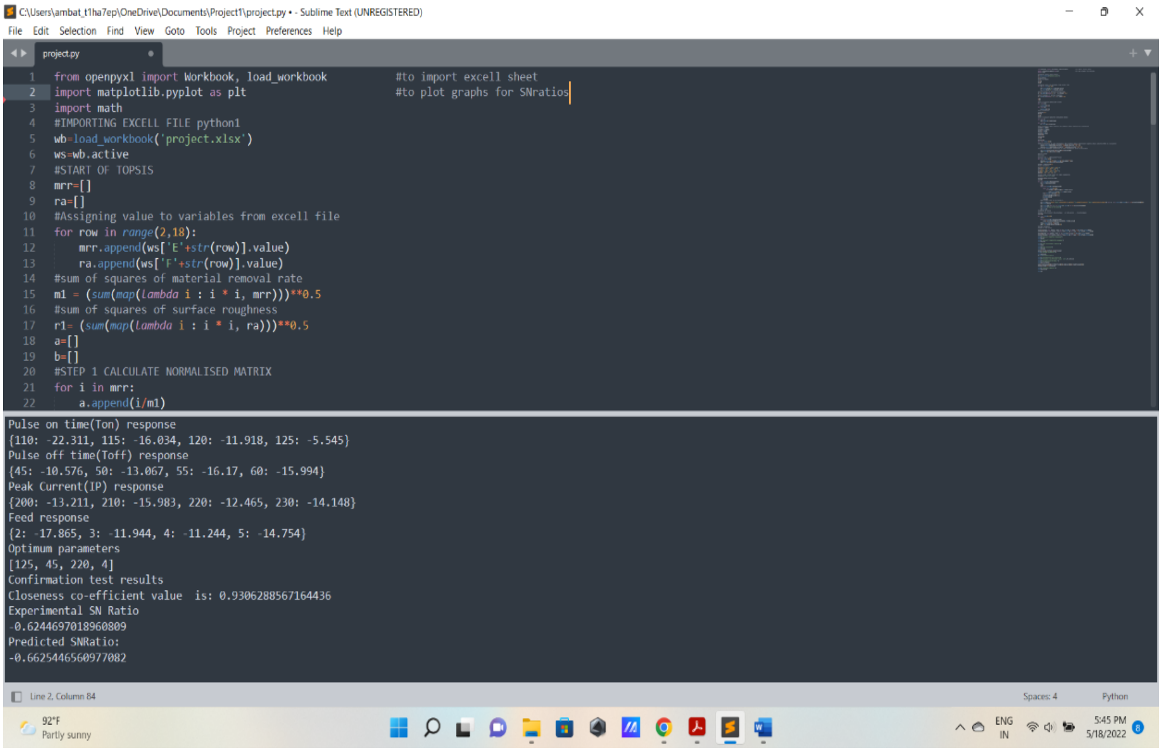

Fig 5.1 Python code snippet

CHAPTER 6

RESULTS AND DISCUSSION

6 RESULTS AND DISCUSSION

In the previous chapter the experimentation setup and machining process was explained and, in this chapter, how results, graphs obtained are discussed in detail.

6.1 TOPSIS results

After applying TOPSIS method to the output parameters i. e surface roughness and material removal rate, we get closeness co-efficient (CC_i) values

Table 6.1 Closeness co-efficient values

T_{on} (µs)	T_{off} (µs)	IP (A)	FEED m/min	CC_i
110	45	200	2	0.088109
110	50	210	3	0.097366
110	55	220	4	0.093259
110	60	230	5	0.043122
115	45	210	4	0.201006
115	50	200	5	0.168227
115	55	230	2	0.087661
115	60	220	3	0.209588
120	45	220	5	0.465615
120	50	230	4	0.421046
120	55	200	3	0.215212
120	60	210	2	0.097992
125	45	230	3	0.930122
125	50	220	2	0.353144
125	55	210	5	0.33154
125	60	200	4	0.714421

6.2 Taguchi analysis

Analysis of experiments was done using the Taguchi method and S/N ratios are obtained for single response CC_i obtained from multiple responses by TOPSIS were shown in the below table.

Table 6.2 S/N Ratio for closeness coefficient CCi

T_{on} (µs)	T_{off} (µs)	IP (A)	FEED m/min	CC_i	SNRA	Fits SNRA
110	45	200	2	0.088109	-21.0996	-22.1074
110	50	210	3	0.097366	-20.2319	-21.4494
110	55	220	4	0.093259	-20.6062	-20.3344
110	60	230	5	0.043122	-27.306	-25.3514
115	45	210	4	0.201006	-13.9358	-11.9814
115	50	200	5	0.168227	-15.4821	-15.2104

115	55	230	2	0.087661	-21.1438	-22.3614
115	60	220	3	0.209588	-13.5727	-14.5814
120	45	220	5	0.465615	-6.63947	-7.85736
120	50	230	4	0.421046	-7.51342	-8.52136
120	55	200	3	0.215212	-13.3427	-11.3874
120	60	210	2	0.097992	-20.1762	-19.9044
125	45	230	3	0.930122	-0.6292	-0.65736
125	50	220	2	0.353144	-9.04095	-7.08636
125	55	210	5	0.33154	-9.58929	-10.5964
125	60	200	4	0.714421	-4.92092	-4.13836

6.3 Analysis of variance (ANOVA)

ANOVA was used to determine the design parameters significantly influencing the response parameters. Analysis of variance (ANOVA) results of mass loss were shown in Table-5.2. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of TABLE-5.2 shows the percentage of contribution of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained, that T_{on} was the most significant parameter having the highest statistical contribution (70.648%) followed by Feed (12.952%) followed by T_{off} (10.085%) and IP (3.283%). Contribution for each source parameter is calculated as follow

$$\%\ Contribution = \frac{seq\ SS\ of\ each\ parameter}{Total\ of\ each\ parameter} * 100$$

Table 6.3 Analysis of variance for S/N ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %
T_{on}	3	596.07	596.07	198.36	23.31	0.014	70.648
T_{off}	3	85.09	85.09	28.362	333	0.175	10.085
IP	3	27.70	27.70	9.233	1.08	0.475	3.283
Feed	3	109.28	109.28	36.427	4.21	0.132	12.952
Residual	3	25.57	25.57	8.524			3.030
TOTAL	15	843.71					100

6.4 Response table for signal to noise ratio for larger is the best condition

Table 6.4 Response table for signal to noise

Level	T_{on}	T_{off}	IP	FEED
1	-22.311	-10.576	-13.211	-17.865
2	-16.034	-13.067	-15.983	-11.944
3	-11.918	-16.17	-12.465	-11.244
4	-5.545	-15.994	-.14.148	-14.754

6.5 Main Effect Plot for SN Ratio

Use in conjunction with an analysis of variance and design of experiments to examine differences among level means for one or more factor. A main effect is present when different levels of factors affect the response differently. A main effects plot graphs the response mean for each factor level connected by a line.

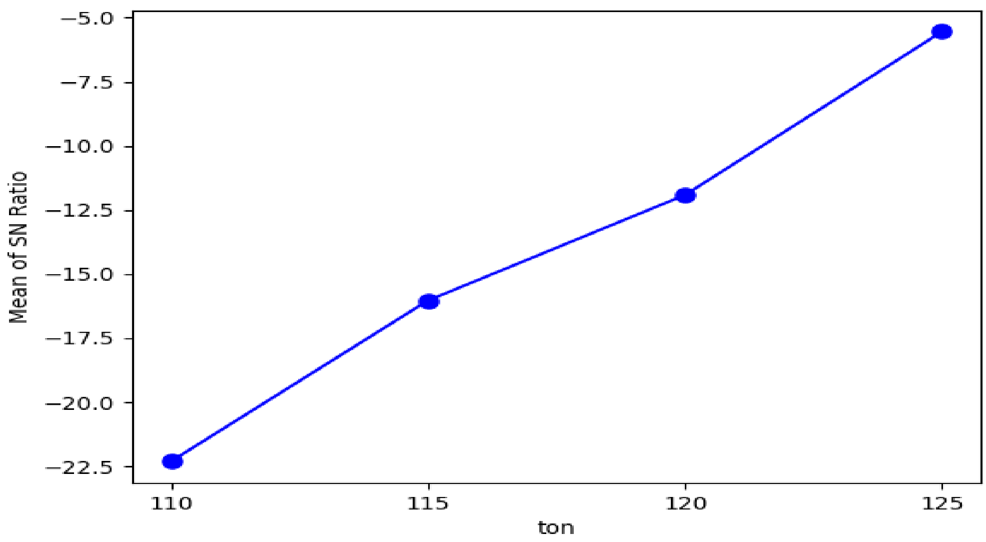

Fig 6.1 T_{on} effects plot

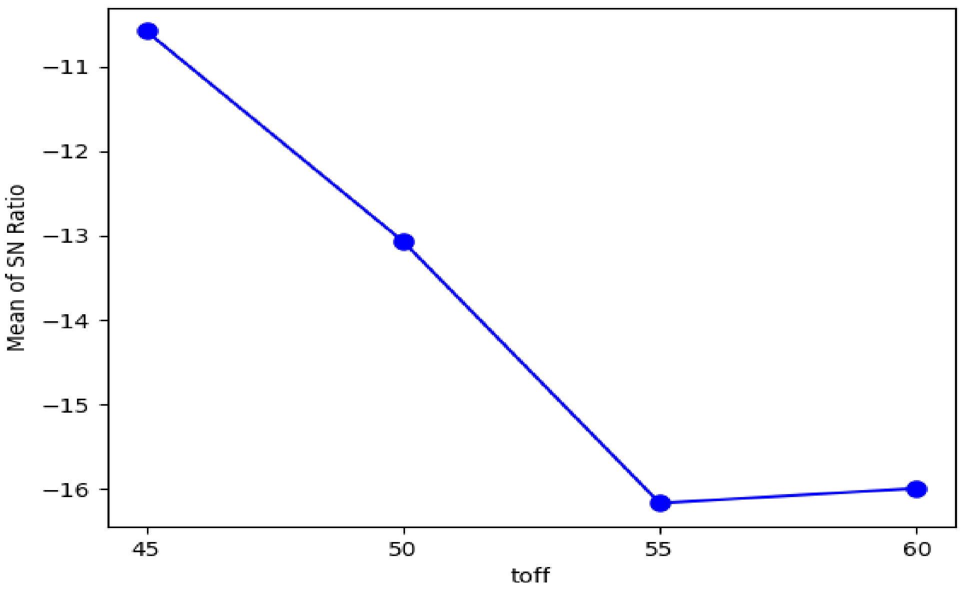

Fig 6.2 Toff effects plot

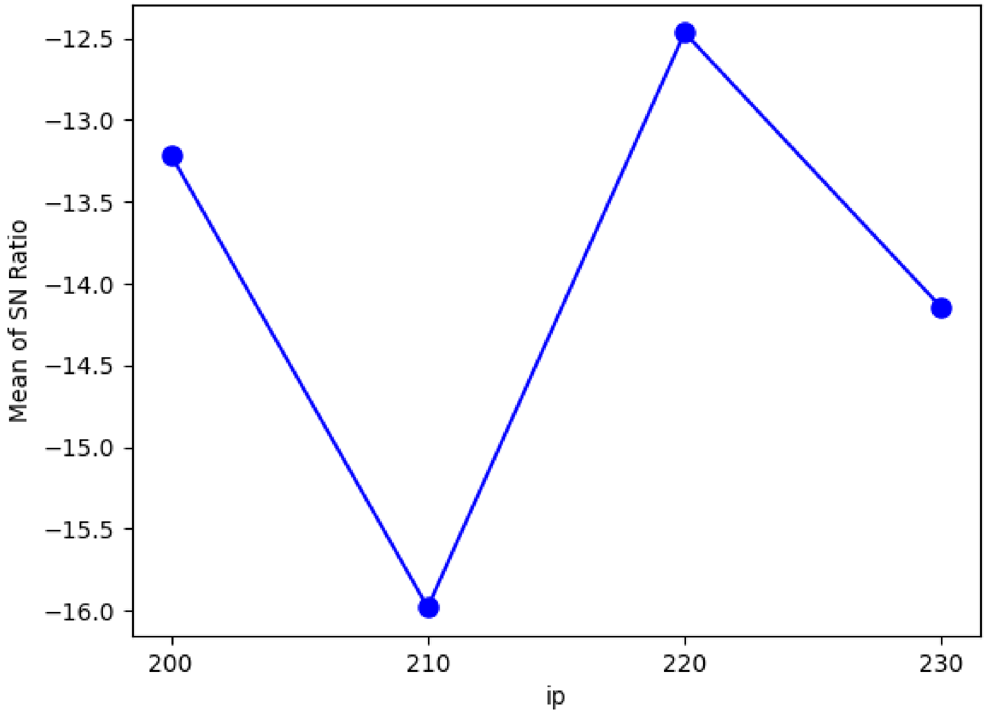

Fig 6.3 IP effect plot

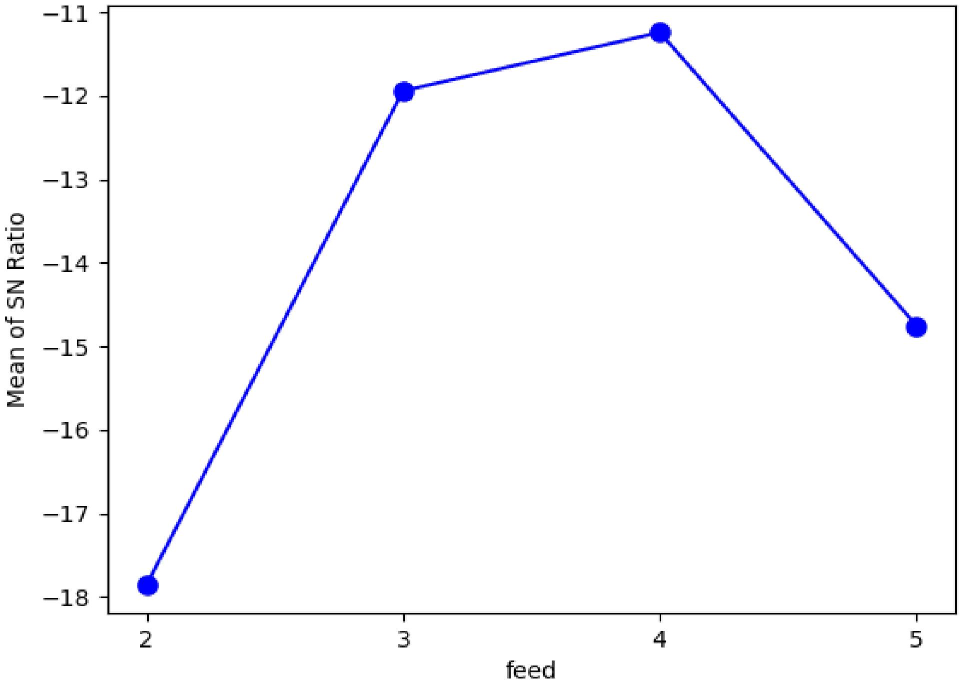

Fig 6.4Feed effect plot

- The main effects plot showing the variation of mean of SN ratios for different process parameters.
- This plot give clear information on how the mean of SN ratios is changing with respect to individual parameters value.
- Mean of S/N ratio of TON is maximum at level 4.
- Mean of S/N ratio of TOFF is maximum at level 1.
- Mean of S/N ratio of IP is maximum at level 3.
- Mean of S/N ratio of wire feed is maximum at level 3.

6.6 Optimum factors based on mean effect plot

Table 6.5optimum factors based on mean effect plot

S.NO	Factor	Level	Corresponding Value	Mean of S/N dB
1	TON	4	125µs	-5.545
2	TOFF	1	45 µs	-10.576
3	IP	3	220A	-12.465
4	FEED	3	4m/min	-11.244

6.7 Predicted S/N ratio

S/N ratio is predicted by using the equation

$$S/N_{Predict} = S/N_{TotalMean} + \Sigma\,(S/N_{meanOptfactor} - S/N_{totalmean})$$

Predicted S/N ratio =-0.662dB

6.8 Confirmation experiment

The conformation experiment is very important in parameter design. The purpose of conformation experiment in the present work was to validate the optimum factors T_{ON4}, T_{OFF1}, IP_3 & $Feed_3$.The experimental results of the confirmation experiment was listed in the below Table

Table 6.6 Results of confirmation test

T_{on} (µs)	T_{off} (µs)	IP (A)	FEED (m/min)	CC_i	s/n Ratio	predicted s/n ratio	% Of Error
125	45	220	4	0.9306	-0.624	-0.662	5.74

CHAPTER 7

CONCLUSIONS

7 CONCLUSIONS

This study has presented the application of multi-response optimization using TOPSIS and Taguchi approach for maximizing the Material removal rate and minimizing surface roughness during the Wire EDM. A program is developed using python and following conclusions were drawn from the experimental and predicted results.

1. Optimum parameters for maximizing the Material removal rate and minimizing surface roughness were obtained i.e., Pulse on time 125µs, Pulse off time 45µs, Wire Feed 4m/min and Peak Current 220A.

2. ANOVA results of the optimum parameters shows that, Pulse on time has high contribution with 70.648% followed by Feed (12.952%) followed by T_{off} (10.085%) and IP (3.283%).

3. Predicted S/N Ratio has been obtained as -0.662dB at optimum parameters.

4. Confirmation experiment was conducted at optimum parameters and S/N ratio was obtained as -0.624dB. The predicted values and experimentally measured values are good in agreement with 5.740% error.

REFERENCES

[1] Ch. Maheswara Rao "EDM Process parameters in Machining SS316 using DEAR method. Journal of Recent Trends in Mechanics" e-ISSN: 2582-3213 Volume-5, Issue-3 (September-December 2020).

[2] G. Rajalakshmi et al ``Optimization of Process parameters of Wire Electrical Discharge Machining on Inconel 825 using Grey Relational Analysis Coupled with Principle Component Analysis." International Journal of Applied Engineering Research ISSN 0973-4562 Volume 8, Number 11.

[3] Kamal Jangra "Simultaneous optimization of material removal rate and surface roughness for WEDM of WCCo composite using grey relational analysis along with Taguchi method." International Journal of Industrial Engineering Computations 2 (2011) 479–490.

[4] Kamal Jangra "Optimization OF Multiple-Machining Characteristics in Wire EDM OF Punching DIE using GREY RELATIONAL Analysis." International Conference on Robust Quality Engineering vol 69 August 2010.

[5] Lokeswara Rao T et al "Optimization of WEDM Process Parameters on Titanium Alloy Using Taguchi Method." International Journal of Modern Engineering Research (IJMER) Vol. 3, Issue. 4, Jul. - Aug. 2013 pp-2281-2286.

[6] M. Raja Roy et al "Optimization of Material Removal Rate and Surface Roughness of MoS2 Reinforced Aluminum Metal Matrix Composite in Wire-EDM Process." International Journal of Engineering Development and Research Volume 6, Issue 4 | ISSN: 2321-9939.

[7] M. Raja Roy et al "Multiple Optimization of Wire EDM Machining Parameters Using Grey Based Taguchi Method for Material HCHCR. International Of Modern Engineering Research" ISSN: 2249–6645 Vol. 4, Iss. 2 Feb. 2014.

[8] M. Geeta Rani et al "Experimental Investigation on Optimization of the Controlling Factors for Machining Al 6061/MoS2 Metal Matrix Composites with Wire EDM." International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22.

[9] M.V.N. Srujan Manohar et al "Optimization of Machining Parameters for AISI 316L And 317L Austenitic Stainless Steels using Eco-Cut Wire-EDM Technique." International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-9, Issue-2.

[10] Mohd Sazali Md Said, "Comparison between Taguchi Method and Response Surface Methodology (RSM) In Optimizing Machining Condition" International Conference on Robust Quality Engineering.

[11] M. Durairaj et al. "Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade 64" (2013) 868 – 877.

[12] Maheswara Rao Ch et al "Optimization of Wire EDM Process Parameters using a Composite Method of AHP based TOPSIS" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181.

[13] Pawan Kumar et al "Optimization of process parameters for WEDM of Inconel 825 using grey relational analysis." Decision Science Letters 7 (2018) 405–416.

[14] S Sivakiran "Effect of Process Parameters on Metal Removal Rate in Wire Electrical Discharge Machining of En31 Steel." International Journal of Engineering Research and Applications Vol. 2, Issue 6, November- December 2012.

[15] S. Vignesh et al "Parameter Optimization of Wire EDM in a Range of Thickness for EN8 Die Steel" International journal for trends in engineering & technology volume 5 issue 2 – May 2015 - ISSN: 2349 – 9303.

.