USE OF TAGUCHI AND GREY RELATIONAL ANALYSIS METHOD TO OPTIMIZE MULTIPLE RESPONSES OF DRILLING PROCESS PARAMETERS OF EN36 HARDENING STEEL.

A project report submitted for the partial fulfilment of the requirements for the award of the degree of

Bachelor of Technology
in
Mechanical Engineering

Submitted by

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CERTIFICATE

This is to certify that the project report entitled **"Use of Taguchi And Grey Relational Analysis Method To Optimize Multiple Responses of Drilling Process Parameters of EN36 Hardening Steel."** being submitted by **R. Shiva Arun Teja (320126520L03), T. Suryapratap (319126520051), B. Lavanya (319126520009), K. Dileep (319126520019), Y. V. Sai Bhaskar (319126520062)** to the Department of Mechanical Engineering, ANITS is a record of bonafide work carried out by them under the esteemed guidance of **Mr. R.Vara Prasad.** The results embodied in the report have not been submitted to any other University or Institute for the award of any degree or diploma.

Project Guide

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ABSTRACT

This research paper presents a novel methodology for optimizing the process parameters of drilling EN36, which is a nickel-chromium-molybdenum based case hardening engineering steel, using an orthogonal array and grey relational analysis that involves multiple responses. Carbide-coated HSS twist drills of different diameters are used for drilling. The study aims to optimize parameters such as spindle speed, feed rate, depth of cut and drill diameter while considering multiple responses, such as Surface Roughness and Material Removal Rate (MRR). Sixteen experimental tests were conducted based on L16 orthogonal Matrix. The grey relational analysis is employed to analyze the interdependence of parameters among multiple performance characteristics effectively. A grey relational grade is obtained from the analysis, which helps in identifying the optimum levels of parameters. The ANOVA is utilized to determine the significant contribution of parameters, while a confirmation test is conducted to validate the results. The findings indicate that the proposed approach effectively improves the drilling process responses.

KEY WORDS: EN 36, Taguchi, ANOVA, Grey Relational Analysis, Material Removal Rate , SurfaceRoughness, L16 Orthogonal Matrix, Optimizing , Orthogonal Array, Process Parameters, Surface Roughness.

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NOMENCLATURE

N = spindle speed in rev/min
F = feed in mm/rev
MRR = Material removal rate
D = diameter of the drill bit in mm
d = depth of cut in mm.
fr = feed in mm/min
Ra = Average Surface Roughness
Rq = Root Mean Surface Roughness
Rz = Ten Point Mean Roughness
P = Number of Parameters
$\xi i(k)$ = Grey Relational Coefficient
γ_i = Grey Relational Grade
Δ_{0i} = Sequencing deviation

METHODOLOGY ADOPTED

1. Literature Review
2. Selection of process parameters are their levels.
3. Selection of quality characteristics for each response variable.
4. Taguchi Design of Experiments
5. Conducting experiments as per the Taguchi Method
6. Taguchi analysis for S/N ratios of responses to the input parameters.
7. Conducting ANOVA, Calculation of degrees of freedom and F-ratio.
8. Grey Relational Analysis.

SOFTWARE REQUIRED

1. Minitab 17

1. INTRODUCTION

Drilling operations is for metal removal operation at minimum cost consistent with the required quality levels. The attainment of his straightforward objective can present challenges to those responsible for establishing and maintaining efficient production operation. In this research work, Material Removal Rate (MRR) and Surface Roughness of the work piece (EN 36) resulted by CNC Drilling Machine are studied procedure to find out the solution (optimum parameters).

Productivity can be interpreted in terms of material removal rate in the machining operation and quality represents satisfactory yield in terms of product characteristics as desired by the customers. The quality of design can be improved by improving the quality and productivity in companywide activities. Quality and Productivity are two important factors which are interrelated with each other in any machining operation.

Taguchi parameter design offers a systematic method for optimization techniques of various parameters with regard to performance, quality and cost. Taguchi design is proved to be an efficient tool to produce high quality products at very less cost. The objective of Taguchi robust design is to determine the optimal parameter settings and making the process performance insensitive to various sources of variations. The approach can economically satisfy the needs of the problem solving and design optimization. Taguchi technique allows the process optimization with minimum number of experiments without need for process model development. Thus, by this method, it is possible to reduce the time and cost for experimental investigations and thus enhance the performance characteristics.

Drilling operation is evaluated based on the performance characteristics such as surface roughness, material removal rate (MRR), tool wear, tool life, cutting force, hole diameter error, power consumption and are strongly correlated with the drilling parameters such as speed, feed, depth of cut, and tool geometry. In this context, four parameters spindle speed, feed, depth of cut and drill tool diameter are selected as controllable parameters and parameters like MRR and Surface Roughness are considered as the required productivity & quality characteristic responses.

1.1 BASIC PRINCIPLES OF MACHINING

Machining parameters that can affect the process are:-

a) **Cutting Speed**

b) **Feed**

The major factors are considered for selecting cutting speed, feed are:-

- **Nature of cut**
    - Continuous cut like turning, boring, drilling etc., are done at higher cutting speed.
    - Shock initiated cuts in shaping machine, planning machine, slotting machine etc., are conducted at lower cutting speed.
    - Intermittent cuts as in milling, hobbing etc are done at quite lower speed for dynamic loading.
- **Work Material** (Type, strength, hardness, heat resistance, toughness, chemical reactivity etc.,)
    - Harder, stronger, heat resistant and work hardenable materials are machined at lower cutting speed.
    - Soft, non-sticky and thermally conductive materials can be machined at relatively higher cutting velocity.
- **Cutting tool material** (Type (HSS, Carbide, Ceramics), strength, hardness, heat and wear resistance, toughness, chemical stability, thermal conductivity etc,)
    - HSS tools are used at within 40 m/min only in turning mild steel whereas for the same work cemented carbide tools can be used at cutting speed 80 to 300 m/min
    - High performance ceramic tools and cBN tools are used at very high speed in machining steels of different strength and hardness.
    - Diamond tools can be used in machining various materials at cutting speed beyond 500 m/min.
- **Cutting fluid application**
    - Proper selection and application of cutting fluid may allow increase in cutting speed by 20 to 50%.
- **Purpose of machining**
    - Rough machining with large MRR is usually done at relatively low or moderate velocity.

  - Finish machining with small feed and depth of cut is usually done at high cutting speed.

- **Kind of machining operation**
  - Unlike turning, boring etc ., the operation like threading, reaming etc are carried out at much lower (20 to 50%) cutting velocity for achieving quality finish
- **Capacity of the machine tool**
  - Powerful, strong, rigid and stable machine tools allow much higher cutting speed
  - Power, torque and accuracy of the machine.
- **Condition of the machine tool**
  - Cutting velocity is kept lower than its normal value stipulated for a given tool – work material pair, if the machine tool is pretty old and / or having limitations due to wear and tear, backlash, misalignment, instability etc.

1.2 CNC DRILLING

Computer Numerical Control (CNC) drilling machine is a specialized and versatile form of automation, it is initially developed to control the motion and operation of machine tools. CNC by means of operating a machine through the use of discrete numerical values fed into the machine where the required ‘input’ technical information is stored on a kind of input media. The machine follows a predetermined sequence of machining operations at the predetermined speeds necessary to produce a work piece of the right shape and size and thus according to completely predictable results.

The definition of CNC drilling machine given by Electronic Industrial Association (EIA) is ***“A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data”.*** In simple words, a CNC drilling machine receives numerical data, interpret the data and then control the action accordingly.

1.3 ADVANTAGES OF CNC DRILLING MACHINES

- CNC machines can be used continuously 24 hours a day, 365 days a year and only need to be switched off for occasional maintenance.

- CNC machines are programmed with a design which can then be manufactured hundreds or even thousands of times. Each manufactured product will be exactly the same.
- Less skilled / trained people can operate CNCs unlike manual radial drilling machines.
- Training in the use of CNC is available through the use of ‘virtual software’. This software allows the operator to practice using the CNC machine on screen of a computer.
- In CNC machine high precision is maintained. High metal removal rates & good surface finish are achieved through CNC machine.

1.4 APPLICATIONS OF CNC DRILLING

Aerospace

Thousands of parts are created using CNC machines for the airline industry including: airline engine governors, fuel bodies and transmissions, landing struts, aircraft structures and more.

Automotive

Automotive parts are created by CNC machines for OEM and aftermarket parts. Some of which include: engine cylinder heads, aluminum drive housings, flywheels, engine blocks, piston rods, wheels, water pumps and many more.

Agriculture

The farm equipment industry relies heavily on parts created by CNC machines, including transmissions, gearbox cases, transmission housings, cast parts and differential cases.

Construction

Tools used in the construction industry have precision are parts created by CNC machines.

Industry

Tube Sheet drilling of Heat Exchangers, Pressure Vessels etc.,

1.5 OBJECTIVE OF WORK

The objective of the present work is to determine the optimum drilling parameters and also which factor has major influence on EN 36 steel during CNC Drilling operation. ANOVA is carried out on response variables and factors influencing on each response variable are determined. Grey Relational Analysis is carried out to convert multi-objective problem to single objective problem and grey grades are determined to identify the optimum combination of factors.

1.6 ORGANISATION OF THESIS

The present work is organized in the following chapters as mentioned below:-

Chapter-1 of the thesis deals with brief introduction of CNC machine, it's application in manufacturing industry and the objective of the work.

Chapter-2 provides a review of literature related to the present thesis.

Chapter-3 explains the proposed methodology, gives the overview of response variables, factors influencing the response variables and also about Grey Relational Analysis.

Chapter-4 gives an overview of the experimental set up, selection of work piece material and testing procedure.

Chapter-5 results are derived then followed by discussion regarding the results.

Chapter-6 presents the conclusions derived from the previous chapter.

2. LITERATURE REVIEW

W.H.Yang et al.,[1] in his study to find the optimal cutting parameters for turning operations using Taguchi method. An orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) are employed to investigate the cutting characteristics of S45C steel bars using tungsten carbide cutting tools.

Deng and Chin et al.,[2] investigate the roundness of holes in BTA deep-hole drilling on AISI 1045 steel by Taguchi methods. The machining parameters include tool diameter, shaft length, feed rate and rotational speed, day of the week (as noise factor). Result shows that strongly influence factors were feed rate, rotational speed and tool diameter, moderate influence of shaft length and no or little influence of noise factor on the roundness of the hole.

A. Noorul Haq et al.,[3] investigated the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal array with grey relational analysis. Drilling tests are carried out using TiN coated HSS twist drills of 10 mm diameter under dry condition. In this study, drilling parameters namely cutting speed, feed and point angle are optimized with the considerations of multi responses such as surface roughness, cutting force and torque. A grey relational grade is obtained from the grey analysis. Based on the grey relational grade, optimum levels of parameters have been identified and significant contribution of parameters is determined by ANOVA.

Palani kumar et al.,[4] find out the effect of spindle speed, feed rate & two different cutting tool i.e. HSS twist drill and 4-flute cutters on Delamination, when Drilling of GFRP Composites by forming L9 Orthogonal Array, using Taguchi methods and Response Surface Regression methods. Found that feed rate is the dominant parameter, which affects the delamination in drilling of GFRP composites, in both Drills. To reduce delamination feed rates (major parameter) should be lower or preferred.

Zhang and Chen et al.,[5] study effect of feed rate, spindle speed, peck rate,& tool type also noise factors were shop vibration and the presence or absence of magnetism in the work piece material on surface roughness in a (CNC) drilling of 1018 low carbon steel plates forming L9 orthogonal array & Taguchi method. The effect of tool type and spindle speed on surface quality were greater than the effect of feed rate, also different peck rates had an impact on the surface finish of the drilled holes, work piece magnetism & vibration did not generate significant impacts on drilling hole surface roughness.

E. Kilickap et al.,[6] investigated the Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite using Expert Systems with Applications. The input parameters were cutting speeds, feed rate and point angle. The best results of the delamination were obtained at lower cutting speeds and feed rates.

M. Kaladhar et al.,[7] investigated the Application of Taguchi Method and utility concept in solving the Multi-objective problem when turning AISI 202 Austenitic Stainless Steel. From the results it is concluded that feed has more influence on the parameters followed by speed and depth of cut.

C. Dhavamani et al.,[8] conducted the Optimization of Machining Parametersfor Aluminum & Silicon carbide composite using Taguchi method, ANOVA, F-test Genetic Algorithm in CNC Drilling Machine, the input parameters taken are Drilling Speed (m/min), Feed rate (mm/rev), Diameter of cut (mm) whereas the output parameters were MRR, Surface finish, Minimization of specific energy and Flank wear. It is concluded that the application of multi-objective optimization which is based on Taguchi method increase the flexibility on selecting the optimal cutting parameters for drilling process of composite materials.

J. Pradeep Kumar et al.,[9] investigated the Effect of drilling parameters on surface roughness, tool wear, material removal rate and hole diameter error in drilling of OHNS in CNC Drilling Machine. The input parameters were Cutting speeds (m/min), Feeds (mm/rev) and Drill diameters (mm) whereas the output parameters were Surface finish, Tool wear, Material removal rate, Hole diameter error. It is concluded that through ANOVA, it is found that the feed and speed are important process parameters to control surface roughness, tool wear, material removal rate and hole diameter error. Further study could consider more factors (drill properties [point angle, helix angle, flute number, types of drills] and run out of drill, thrust force, toques etc.)

Kadam Shirish et al.,[10] conducted the experiment on Application Of Taguchi Method in the Optimization Of Drilling Parameters on EN-24 steel blocks work piece were Ø150 x 45 mm in CNC Drilling machine. The input parameters were Speed (m/min), Feed (mm/rev) & Depth of Hole (mm) whereas Minimum surface roughness and maximum tool life. It is concluded that the use of high cutting speed, low feed rate and low depth of hole leads to better surface finish. In dry drilling high speed, low feed are recommended for higher surface finish of hole.

M.A. Amran et al.,[11] studied the Effects of machine parameters on Aluminum alloy in CNC Drilling Machine using response surface method in drilling process. The input parameters were Spindle Speed (rpm), Feed Rate (mm/min), Drill diameter (mm) and output parameters Surface Roughness. He concluded that the appropriate combination of spindle speed, feed rate and drill diameter were very important for drilling process. The optimization performed found that the parameters that affects surface roughness was spindle speed followed by drill diameter and feed rate.

Arshad Noor et al.,[12] conducted the Optimization of Deep Drilling Process Parameters of AISI 321 Steel using Taguchi Method, ANOVA on CNC machine. The input parameters were cutting fluid, speed, feed and hole-depth whereas the output parameters were minimum surface roughness. It is concluded that except hole-depth, cutting parameters such as speed, feed, and cutting fluid mainly influenced the surface roughness in deep drilling of AISI 321 austenitic steel bars.

G. Gangadhar et al.,[13] conducted the Experimental Approach of CNC Drilling Operation for Mild Steel Using Taguchi Design & ANOVA with input parameters Spindle Speed (rpm) Feed rate (mm/min), Drill tool point and output parameters were MRR, Circularity. It is concluded that Material removal rate (MRR) decreases when spindle speed, feed and tool diameter decrease. Circularity Error is mostly affected by spindle speed and feed rates. If the value of spindle speed and feed rate increase, Error will also increase. Increased Spindle speed, feed rate and tool diameter increases the quality of hole.

Suman Chatterjeea et al.,[14] conducted the NSGA-II Approach of Optimization to Study the Effects of Drilling Parameters in AISI-304 Stainless Steel using response surface methodology in CNC Machine. The input parameters were SpindleSpeed (RPM), Feed rate (mm/rev), Drill Diameter (mm) whereas the output parameters were circularity of hole Burr height. It is concluded that as the drilling of AISI 304 stainless steel with TiN-PVD coated drill bit is a costlier and time consuming process, so there is requirement of optimization of process parameters that will benefit in growth of production rate by minimizing the machining time and cost.

Tamilselvan et al.,[15] performed experimentation on Optimization of Process Parameters of Drilling in Ti-Tib Composites on CNC Drilling Machine using Taguchi, Anova Technique with the input parameters taken were Spindle Speed, Feed rate, Process and Drilling material. Output Parameters are thrust force, overcut, taper & circularity. The conclusion he stated was the thrust force decreased with the increase in spindle speed. The increase in spindle speed plays a predominate role in the drastic reduction of overcut. Higher feed rate engendered to lesser taper angle. . Spindle speed had the predominant contribution towards improving circularity when compared to the other three process parameters.

YD Chethan et al.,[16] conducted the Parametric optimization in drilling EN-8 tool steel and drill wear monitoring using machine vision applied with taguchi method, ANOVA in Radial Drilling Machine with input parameters Spindle Speed (RPM), Feed rate (mm/rev) & Drill Diameter (mm) whereas output parameters were Tool wear. It is concluded that combination of process parameter optimization and tool wear monitoring can give satisfactory response for achieving desired results.

Jitender Malik et al.,[17] investigated the Evaluation of MRR in CNC Drilling through 0ptimization of En-8D using Taguchi Method, the input parameters were Spindle Speed & Feed whereas the output parameters are MRR, Surface Roughness (Ra). It is concluded that the order strength for S/N ratio for surface roughness is spindle speed and feed. The order strength for mean surface roughness is also spindle speed and feed.

Syed Siraj Ahmed et al.,[18] conducted the experimental Analysis of Material Removal Rate in Drilling of 41Cr4 in CNC Drilling machine by a Taguchi experimental design method, analysis of variance (ANOVA) and regression analysis. The input parameters were Spindle Speed (rpm), Feed rate (mm/min) and Depth of cut (mm) whereas the output parameters were Material Removal Rate. It is concluded that linear regression equations are developed to predict the values of material removal rate and the predicted values are compared with measured values. Through ANOVA, it is found that the Spindle speed is important process parameters to material removal rate. Thus it is essential to employ suitable combination of Spindle speed and feed so as to reduce the variations.

Ms. Ashvini et al.,[19] investigated the Parametric Optimization of Drilling Machining Process of M.S. Material in CNC Drilling Machine by using Factorial Regression Method and the input parameters were Spindle Speed (RPM), Feed Rate (mm/min) & Depth of Cut (mm) where as the output parameters were Material removal rate. It is concluded that the effect of Depth of Cut on the MRR value is significant and observed that the effect of Depth of Cut as well as spindle speed on the SR value is significant.

Sumesh A S et al.,[20] experimented the Optimization of Drilling Parameterson Radial Drilling machine for Cast Iron to find Minimum Surface Roughness Using Taguchi Method, ANOVA. The input parameters were Spindle speeds (RPM), Feeds (mm/rev) and Drill diameters (mm). It was identified that a spindle speed of 80 rpm, drill diameter of 4mm and a feed rate of 0.1 mm/rev is the optimal combination of drilling parameters that produced a high value of S/N ratios of hole roughness.

Scope of work from Literature Survey :

Numerous investigations have been carried out in the fields of optimization of working parameters for drilling operations in CNC drilling machines considering different input parameters like speed, feed, depth of cut, drill diameter etc., to find the best output parameters like Material Removal Rate (MRR) and Surface Roughness etc., to find the best output parameters like Material Removal Rate (MRR) and Surface Roughness etc., are studied , the importance of optimization and applications are also understood. Also extensive research papers are carefully gathered and studied for the purpose of optimization of CNC Drilling specifically. These were very helpful in defining the methodogy and experimental study and plotting the results for the current work.

3. METHODOLOGY

3.1 INTRODUCTION

In the present work experiments are carried out and measurement of Material Removal Rate and Surface roughness are calculated. In this present chapter analysis methodology used for obtaining better response parameters are briefly discussed. In modern industrial environment a numerous kinds of investigations done for the improvement of product quality in the field of manufacturing. Some have few factors to be considered, some have many. A majority of experiments fall in the category in same number of levels. In the conventional technique of varying one factor at a time, lot of experimental data can be obtained. This way of experimentation not only consumes lot of time but also poses a challenge to the investigator for deriving appropriate conclusion from the huge experimental data. Design of Experiments (DOE) is at ever rescue for planning systematic experimentation and arriving at meaningful conclusion without being inundated in huge set of experimental data. DOE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of factors.

3.2 METHODOLOGY

The steps involved in the methodology are given below:

- Selection of process parameters and their levels.
- Selection of quality characteristics for each response variable.
- Taguchi Design of Experiments.
- Conducting experiments as per the Taguchi method.
- Taguchi analysis for S/N ratios of responses to the optimal parameters.
- Conducting ANOVA, calculation of degrees of freedom and F-ratio.
- Grey Relational Analysis for converting multi-objective into a single objective function to obtain optimal process parameter for both MRR and Surface roughness.
- Determining the results at optimum condition
- Confirmation of experiments

3.3 SELECTION OF PROCESS PARAMETERS AND THEIR LEVELS

Selection of right combination of process parameters and setting the range of the process parameters is very important step in machining process. In this work the process parameters are taken as Fixed and Controllable.

In this present work, tool geometry, work piece properties and mechanical properties are considered as fixed parameters which will not change throughout the investigation whereas Spindle speed, feed, depth of cut & drill diameter are considered as the controllable parameters which will be affected with the process of investigation.

In order to conduct the experiment four input parameters namely Spindle speed, feed, depth of cut & drill diameter at four levels i.e. level -1, level-2, level 3 and level 4 are selected. The selected input parameters for the experiment with their limits, notations and units are given below:-

Table 3.1: Process Parameters and their levels

Parameter	Units	Level-1	Level-2	Level-3	Level-4
Spindle Speed (n)	rpm	1000	1500	2000	2500
Feed rate (fr)	mm/min	50	150	200	250
Depth of cut (d)	mm	6	8	12	15
Drill diameter (D)	mm	10	12	15	18

3.4 SELECTION OF QUALITY CHARACTERISTICS FOR RESPONSE CHARACTERISTICS

3.4.1 Material Removal Rate (MRR)

In any machining operation, material removal rate is an important factor to enhance the productivity. Therefore the MRR is investigated with optimum value of current. Hence the quality characteristics for Material Removal Rate is “larger the better”.

Theoretical MRR= (π/4*D2*f*N) mm^3/min ------- (1)

Where,

MRR=Material removal rate

D=diameter of the drill bit in mm

F=feed in mm/rev
N=spindle speed in rev/min

Experimental MRR= ((Initial wt of work piece **(**gms**))-(**final wt of work piece (gms**))) / ((**density in gms**)*(**Machining time **(**min**)))** -------------------(2)

3.4.2 Surface Roughness

The surface roughness plays a vital role in the functional aspect and durability of any product. In all machining processes, it is mostly aimed to achieve better surface finish. Therefore the surface roughness is considered as a quality characteristic. The quality characteristic of Surface Roughness is “Smaller the Better”.

3.4.2.1 Surface Topography

Surface can be defined as object as object is the boundary which separates that object from another substance. Its shape and extent are unusually defined by a drawing by a drawing or descriptive specifications. The surfaces are classified in three types as: Nominal Surface, Real Surface and Measured Surface. Nominal Surface is the intended surface. The shape and extent of nominal surface are usually shown and dimensional on a drawing. Real Surface is the actual boundary of an object. It deviates from the nominal surface as a result of the process that created the surface.

3.4.2.2 Surface Texture:

Surface Texture is the combination of fairly short wavelength deviations of a surface from the nominal surface. Texture include roughness, waviness and flaws i.e., all of the deviations that are shorter in wavelength than from error deviations.

a) Roughness (Primary texture)

Relatively fine-spaced irregularities on surface produced by machining and abrasive operations, the irregularities produced by the cutting action of tool edges, abrasive grains and by the feed of machine tool are roughness. Roughness may be considered as being superposed on a wavy surface.

b) Waviness (secondary texture)

Waviness is the surface irregularities which are of greater spacing than roughness. On machined surface such irregularities may result machined surface such irregularities may result machine and work deflections, vibrations etc. Illustration of waviness can be seen in fig. 3.1.

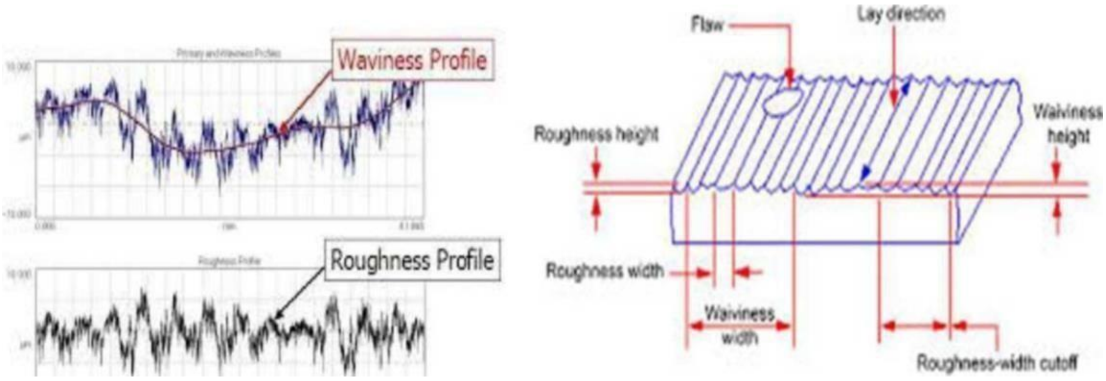

Figure 3.1: Illustration of waviness

c) Flaws

Irregularities which occur at one place or at relatively in frequent intervals on the surface, e.g., a scratch, ridge, hole, crack etc.

d) Lay

The direction of predominant surface pattern.

3.4.2.3 Measured Profile:

Measured profile is a representation of real profile obtained with the help of some measuring instrument. This distinction between "real" and "measure" Is made because no measurement will give exact real surface.

Several commercial available instruments, called Surface profilometer are used to measure and record surface roughness. The most commonly used instrument features a diamond stylus. This travels along a straight line over the surface. The distance that the stylus travels is called as Cut off. Cut off generally ranges from 0.08mm to 25mm. Generally most of the applications 0.8mm are used.

3.4.2.4 Average Surface Roughness:

Roughness is the fine irregularities of the surface texture resulting from the production process or material condition. Roughness average (R_a) is also known as arithmetic average. Surface Roughness (R_a) is the arithmetic average of the absolute values of the measured profile height deviations divided by the evolution length (L). For graphical determination of roughness average, the height deviations are measured normal or perpendicular to the chart line. Roughness average is expressed in micrometers (µm). A micro meter is one millionth of a meter (0.000001 meter).

3.4.2.5 Root Mean Surface Roughness:

Root Mean Surface Roughness (R_q) of a surface is calculated from another integral of the roughness profile. Root Mean Square Roughness (R_q) is expressed in micrometers (µm).

3.4.2.6 Ten Point Mean Roughness:

Ten Point Mean Roughness (R_z) is a section of standard length is sampled from the mean line from the roughness chart. The distance between the peaks and valleys of the sampled line is measured in the y-direction.

3.4.2.7 Factors affecting the Surface Roughness:

Whenever two machined surfaces come in contact with one another the surface quality of mating parts play an important role in the performance and the wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon number of factors. The major machining variables which affect the surface roughness are mentioned below:-

- Speed
- Feed
- Depth of Cut
- Drill diameter

Speed: is the rpm with which the drill bit is rotation with respect to the work piece. The work piece material and drill bit material affects it along with the diameter of cut, position of cut on the work piece.

Feed Rate: When drilling in a CNC machine the feed rate must be determined. Feed: we in mechanical terms measure by the amount of material scrapped off when a push is given to drill bit inside the work piece. This is the distance by which a drill bit moves along the axis of the cut in a single push. This is very crucial as it also is prime reason for the breaking of the drill bit.

Depth of Cut: is the size of cut we need to make. There are different types of cuts, we generally make in the drilling operation, through hole 10 mm depth etc.

Drill Diameter: The drill bit is usually a rotary cutting tool, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. The diameter of drill bit is the drill diameter. Eg. Drill diameter 10, 12, 15, 18 mm etc.

The various other factors which affect surface roughness are tool geometry, work piece, tool material combination and their mechanical properties, quality, type of machine tool used, auxiliary tooling, lubricant used and vibration between the work piece.

3.4.2.8 Surface Roughness Tester

Portable surface roughness tester was used in the present investigation. It consists of stylus through which one can calculate the surface roughness value by moving the stylus front and back on the machined surface, the roughness of the surface will be considered as average of all. The equipment used for measuring the surface roughness is shown in fig.3.2.

Figure 3.2: Surface Roughness Tester

3.5. DESIGN OF EXPERIMENTS (DOE)

Design of Experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. It is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. It is also useful to combine the factors at appropriate levels, each with the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results.

3.5.1 Advantages of Design of Experiments (DOE)

1. Number of trials is significantly reduced.
2. Optimal setting of the parameters can be found.
3. Qualitative estimation of parameters can be made.
4. The effect of parameters on the characteristics of the process can be found out.

3.5.2 Different DOE Techniques

1. Full factorial technique.
2. Fractional factorial technique.
3. Taguchi orthogonal array.
4. Response Surface method.

In this present work, Taguchi orthogonal array method is selected to find the optimum process parameters.

3.6 TAGUCHI METHOD

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

The Taguchi method is a technique to find out the optimum values of the control factors to make the product or process get affected minimally by the noise factors. The Taguchi method is mainly based upon the technique of matrix manipulations. The experimental matrices are special orthogonal arrays, which allow the simultaneous effect of several process parameters to be studied efficiently. The purpose of conducting an orthogonal experiment is to determine the optimum level for each factor and to establish the relative significance of the individual factors in terms of their main effects on the response. Taguchi suggests signal-to-noise (S/N) ratio as the objective function for matrix experiments. The S/N ratio is used to measure the quality characteristics as well as the significant machining parameters through analysis of variance (ANOVA). Taguchi classifies objective functions into three categories such as smaller the better type, larger the better type and nominal the best type. The optimum level for a factor is the level that results in the highest value of S/N ratio in the experimental region.

3.6.1 Taguchi Method treats optimization problems in two categories,

[A] Static Problems

Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "Static Problem".

This is best explained using a P-Diagram which is shown below ("P" stands for Process or Product). Noise is shown to be present in the process but should have no effect on the output! This is the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process. The process is then said to have become ROBUST.

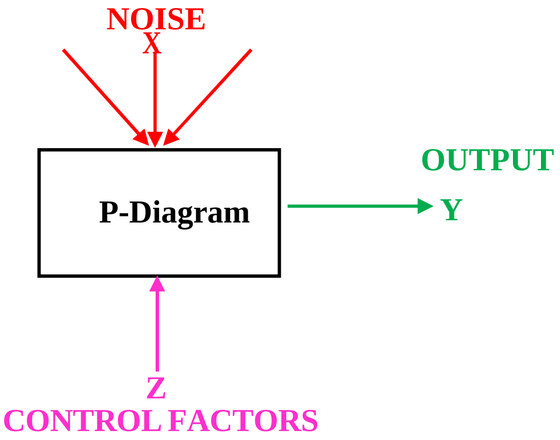

Figure 3.3: P-Diagram for Static Problems

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

(I) Smaller-the-Better

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

This is usually the chosen S/N ratio for all undesirable characteristics like " defects " etc. for which the ideal value is zero. Also, when an ideal value is finite and its maximum or minimum value is defined (like maximum purity is 100% or maximum Tc is 92K or minimum time for making a telephone connection is 1 sec) then the difference between measured data and ideal value is expected to be as small as possible.

(II) Larger-the-Better:

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

This case has been converted to SMALLER-THE-BETTER by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the better case. (for example, agricultural yield)

(III) Nominal-the-Better:

n = 10 Log10 [(Square of mean)/(variance)]

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

Examples are:-

(i) Most parts in mechanical fittings have dimensions which are nominal-the-best type.

(ii) Ratios of chemicals or mixtures are nominally the best type

e.g. Aqua regia 1:3 of HNO3: HCL, Ratio of Sulphur, KNO3 and Carbon in gun powder.

(iii) Thickness should be uniform in deposition /growth /plating /etching.

[B] Dynamic Problems:

If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the "input signal / output" ratio is closest to the desired relationship. Such a problem is called as a "Dynamic Problem".

This is best explained by a P-Diagram which is shown below. Again, the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process- is achieved by getting improved linearity in the input/output relationship.

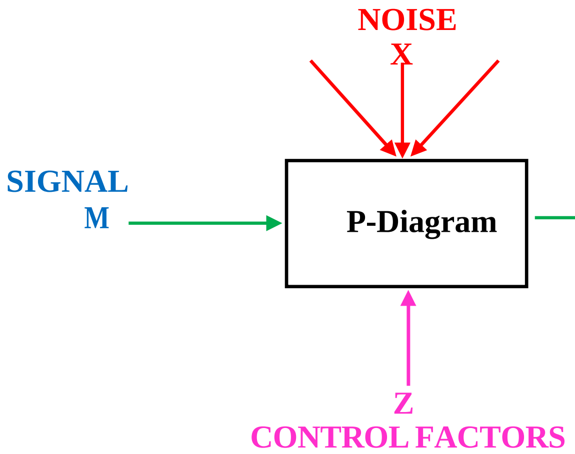

Figure 3.4: P-Diagram for Dynamic Problems

In dynamic problems, we come across many applications where the output is supposed to follow input signal in a predetermined manner. Generally, a linear relationship between "input", "output" is desirable. For example: Accelerator pedal in cars, volume control in audio amplifiers, document copier (with magnification or reduction) various types of mouldings etc. There are 2 characteristics of common interest in "follow-the-leader" or "Transformations" type of applications:-

(i) Slope of the I/O characteristics and

(ii) Linearity of the I/O characteristics (minimum deviation from the best-fit straight line)

The Signal-to-Noise ratio for these 2 characteristics have been defined as follows

(I) Sensitivity {Slope}

The slope of I/O characteristics should be at the specified value (usually 1). It is often treated as Larger-The-Better when the output is a desirable characteristics (as in the case of Sensors, where the slope indicates the sensitivity).

n = 10 Log10 [square of slope or beta of the I/O characteristics]

On the other hand, when the output is an undesired characteristics, it can be treated as Smaller-the-Better.

n = -10 Log10 [square of slope or beta of the I/O characteristics]

(II) Linearity (Larger-the-Better)

Most dynamic characteristics are required to have direct proportionality between the input and output. These applications are therefore called as "TRANSFORMATIONS". The straight line relationship between I/O must be truly linear i.e. with as little deviations from the straight line as possible.

n = 10 Log10 [(Square of slope or beta) / (variance)]

Variance in this case is the mean of the sum of squares of deviations of measured data points from the best-fit straight line (linear regression).

3.6.2 Taguchi's rule for Manufacturing

Taguchi realized that the best opportunity to eliminate variation is during the design of a product and its manufacturing process. Consequently, he developed a strategy for quality engineering that can be used in both contexts.

The process has three stages:

- System design
- Parameter design
- Tolerance design

System Design

This is design at the conceptual level, involving creativity and innovation**.** In this design, an engineer applies scientific and engineering knowledge, which produce a basic functional prototype design. Therefore, System design is defined as an initial functional design. It may be far from optimum in terms of quality and cost.

Parameter Design

Once the concept is established, the nominal values of the various dimensions and design parameters need to be set, the detail design phase of conventional engineering. This is sometimes called robustification. The aim of the parameter design (Montgomery DC, 1997) may be defined, to optimize the settings of the process parameter values. It improves the performance characteristics as well to identify the product parameter values. In this way, it may be seen that the parameter design is the key step in the Taguchi method which achieves high quality without increasing cost.

Tolerance Design

With a successfully completed parameter design and an understanding of the effect that the various parameters have on performance, resources can be focused on reducing and controlling variation in the critical few dimensions. When parameter design is not sufficient for reducing the output variation, the last phase is tolerance design. Narrower tolerance ranges must be specified for those design factors whose variation imparts a large negative influence on the output variation. To meet these tighter specifications, better and more expensive components and processes are usually needed.

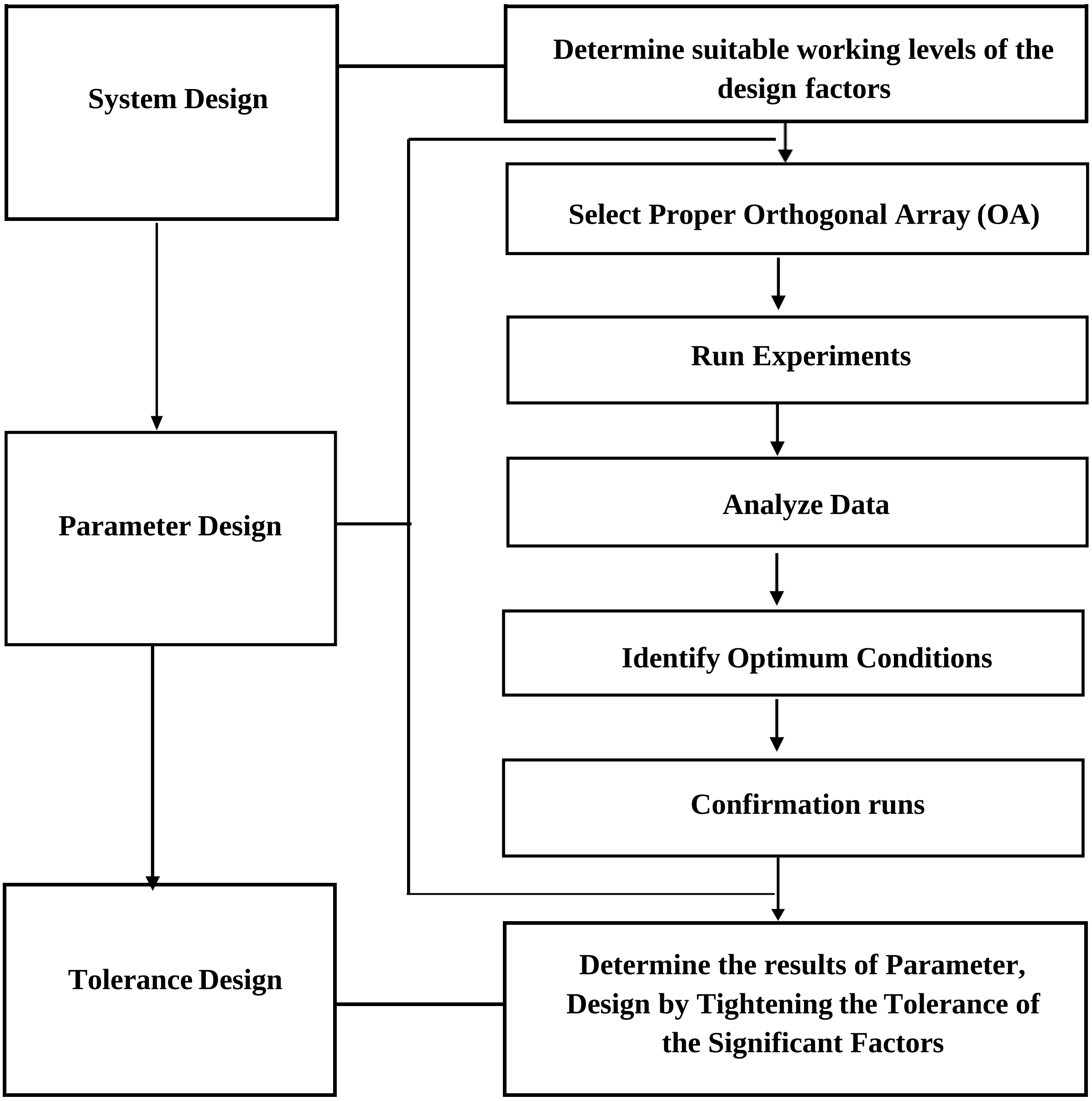

Figure 3.5: Representation of Taguchi design procedure

3.6.3 Mathematical modeling: Orthogonal Array

Taguchi’s L16 Orthogonal Array was used in the design of experiment. There is powerful tool for design of high quality systems, i.e. Taguchi technique which has been used by many researchers tacitly. It also provides simple, efficient and systematic approach to optimize quality, cost and designs for performance. Taguchi technique is efficient tool for designing process that operates consistently and optimally over a variety of conditions. Taguchi technique is an experimental design technique, which is useful in reducing the number of experiments by using orthogonal arrays. Taguchi’s approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community (D.C.Montgomery, 1997). The main objective of Taguchi method is to ensure quality in the design phase. Taguchi technique also allows controlling the variations caused by the uncontrollable factors which are not taken into consideration at traditional design of experiment.

Orthogonal Arrays significantly reduces the number of experimental configurations to be studied (Montgomery1991). The effect of many different parameters on the performance characteristic in a process can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less value can be tested or the values tested can be closer together.

Table 3.2 shows the Array Selector pattern

Levels	Number of Parameters (P)																							
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36		
4	L16	L16	L16	L16	L32	L32	L32	L32	L32															
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50													

3.6.4 Steps in Taguchi Methodology

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

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

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

Step-1: Identify the main function, side effects and failure mode.
Step-2: Identify the noise factors, testing conditions, and quality characteristics.
Step-3: Identify the objective function to be optimized.
Step-4: Identify the control factors and their levels.
Step-5: Select the orthogonal array matrix experiment.
Step-6: Conduct the matrix experiment.
Step-7: Analyze the data, predict the optimum levels and performance.
Step-8: Perform the verification experiment and plan the future action.

3.7 ANALYSIS OF VARIANCE

Analysis of Variance (ANOVA) is a statistical method for determining the existence of differences among several population means. Analysis of variance is particularly effective tool for analyzing highly structured experimental data. Different factors affect the surface defect formation to a different degree. The relative effect of the different factors can be obtained by the decomposition of variance, which is commonly called analysis of variance. ANOVA is also needed for estimating the error variance for the factor effects and variance of the prediction error.

The original ideas analysis of variance was developed by the English Statistician Sir Ronald A. Fisher during the first part of this century. Much of the early work in this area dealt with agricultural experiments where crops were given different treatments, such as being grown using different kinds of fertilizers. The researchers wanted to determine whether all treatments under study were equally effective or whether some treatments were better than others.

The purpose of the analysis of variance is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio can be calculated as:

$$\mathrm{SS_T} = \sum_{n=1}^{n} (\eta_i - \eta_m)^2$$

Where *n* is the number of experiments in the orthogonal array and h*i* is the mean S/N ratio for the *i*th experiment. The total sum of spared deviations SST is decomposed into two sources: the sum of squared deviations SSd due to each design parameter and the sum of squared error SSe. The percentage contribution r by each of the design parameters in the total sum of squared deviations SST is a ratio of the sum of squared deviations SSd due to each design parameter to the total sum of squared deviations SST. Statistically, there is a tool called an *F* test named to see which design parameters have a significant effect on the quality characteristic. In performing the *F* test, the mean of squared deviations SSm due to each design parameter needs to be calculated. The mean of squared deviations SSm is equal to the sum of squared deviations SSd divided by the number of degrees of freedom associated with the design parameter. Then, the *F* value for each design parameter is simply the ratio of the mean of squared deviations SSm to the mean of squared error. Usually, when *F* > 4, it means that the change of the design parameter has a significant effect on the quality characteristic.

3.8 GREY RELATIONAL ANALYSIS

3.8.1 Introduction

In the year of 1980, grey systems theory was brought forward by Professor Deng Ju-long from China Grey analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown. With this definition, information quantity and quality form a continuum from a total lack of information to complete information from black through grey to white. Since uncertainty always exists, one is always somewhere in the middle, somewhere between the extremes, somewhere in the grey area. Grey analysis then comes to a clear set of statements about system solutions. At one extreme, no solution can be defined for a system with no information. At the other extreme, a system with perfect information has a unique solution. In the middle, grey systems will give a variety of available solutions. Grey analysis does not attempt to find the best solution, but does provide techniques for determining a good solution, an appropriate solution for real world problems.

The proposition of Grey theory occurring in the 1990 to 1999 time period resulted in the uses of Grey theory to each field, and the development is still going on. The major advantage of Grey theory is that it can handle both incomplete information and unclear problems very precisely. It serves as an analysis tool especially in cases when there is no enough data. It was recognized that the Grey relational analysis in Grey theory had been largely applied to project selection, prediction analysis, performance evaluation, and factor effect evaluation due to the Grey relational analysis software development. Recently, this technique has also applied to the field of sport and physical education. Grey relational analysis was proposed by Deng in 1989 is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade.

Grey relational analysis is an impacting measurement method in grey system theory that analyses uncertain relations between one main factor and all other factors in a given system. When the experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps for the shortcomings in statistical regression. Grey relational analysis is actually a measurement of the absolute value of data difference between sequences, and it could be used to measure the approximate correlation between the sequences.

3.8.2 Grey Theory

The black box is used to indicate a system lacking interior information. Now a days the black is represented, as lack of information, but the white is full of information. Thus, the information that is either incomplete or undetermined is called Grey. A system having incomplete information is called Grey system. The Grey number in Grey system represents a number with less complete information. The Grey element represents an element with incomplete information. The Grey relation is the relation with incomplete information. Those three terms are the typical symbols and features for Grey system and Grey phenomenon. The Grey relational analysis uses information from the Grey system to dynamically compare each factor quantitatively.

3.8.3 Generation of Grey Relation

The use of Taguchi method with grey relational analysis to optimize drilling parameters with multiple processes responses characteristics includes the following steps:

1. Identify the performance characteristics and cutting parameters to be evaluated.
2. Determine the number of levels for the process parameters.
3. Select the appropriate orthogonal array and assign the cutting parameters to the orthogonal array.
4. Conduct the experiments based on the arrangement of the orthogonal array.
5. Normalize the experiment results.
6. Perform the grey relational generating and calculate the grey relational coefficient.
7. Calculate the grey relational grade by averaging the grey relational coefficient.
8. Analyze the experimental results using the grey relational grade and statistical ANOVA.
9. Select the optimal levels of cutting parameters.

In grey relational analysis, experimental data i.e. measured features of quality characteristics are first normalized ranging from zero to one. The process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated which would result into highest grey relational grade. The optimal factor setting for maximizing overall grey relational grade can be performed by Taguchi method.

3.8.4 Data Pre-Processing

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data.

If the original sequence data has quality characteristic as ‘larger-the-better’ then the original data is pre-processed as ‘larger-the-best’:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

If the original data has the quality characteristic as ‘smaller-the better’, then original data is pre-processed as ‘smaller-the-best’:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Here $x_i(k)$ is the value after grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response, and max $y_i(k)$is the largest value of $y_i(k)$ for the k^{th} response.

3.8.5 Deviation Sequencing

Deviation sequencing is calculated for the obtained pre-processing data by considering ideal value 1. Deviation sequencing can be calculated by using the following formula

$$\Delta_{0i} = 1 - x_i(k),$$

Where Δ_{0i} = Deviation sequencing for the k^{th} pre-process data and $x_i(k)$ = kth pre-process value.

3.8.6 Grey Relational Coefficient [$\xi_i(k)$]

In the next step coefficient $\xi_i$is calculated for all the obtained deviational sequencing data individually, Grey relational coefficient ξi(k) is calculated using the formula:

$$\xi_i(k) = \frac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{0i}(k) + \psi\Delta_{\max}}$$

Where ψ is the distinguishing coefficient $0 \leq \psi \leq 1$, therefore $\psi$is take as 0.5

Δ_{0i} (k) = Deviation sequencing of k^{th} value

$\Delta_{\max}$ = Maximum deviation value form the k^{th} deviation values

$\Delta_{\min}$ = Minimum deviation value form the k^{th} deviation values

3.8.7 Grey Relational Grade

After obtaining the grey relational coefficient in final step relational grade is calculated by the following formula. Here n is the number of process responses.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

The higher value of grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence; therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal. The mean response for the grey relational grade with its grand mean and the main effect plot of grey relational grade are very important because optimal process condition can be evaluated from this plot. For getting the contribution of each parameter ANOVA is performed by using Statistical tool and Taguchi analysis is done to find out S/N ratio, for each grey relational grade value. Optimal process parameters and their predicted values are calculated. And confirmatory test is carried out to compare the S/N ratio of obtained with the predicted S/N ratio.

3.9 SUMMARY

Optimization methodology, selection of process parameters, selection of orthogonal array by Taguchi approach (DOE), ANOVA and Grey Relational Analysis are explained in the present chapter.

4. EXPERIMENTAL SETUP

A number of experiments are conducted to study the effects of various drilling parameters on CNC drilling machine. These studies have been under taken to investigate the effects of Spindle Speed, Feed Rate, Depth of Cut and Drill diameter on Metal Removal Rate (MRR) and Surface Roughness characteristics for EN 36 material which is machined by CNC drilling machine using HSS twist drill carbide coating. This chapter deals with the experimental setup details used in the present work.

4.1 CNC MACHINE AND ITS SPECIFICATIONS

All the experiments have been conducted on AGNI BMV 45 T20 CNC machine. Z axes is servo controlled and can be programmed to follow an NC code which is fed through the control panel, X and Y axes are manually controlled. All these axes have an accuracy of 0.005 mm. Machining time is displayed online during the machining. Through NC code, machining can be programmed to occur to a fixed Depth of Cut.

Figure 4.1: CNC Machine AGNI BMV 45 T20

The following table 4.1 gives the description of the specifications of the CNC machine AGNI BMV 45 T20. Table 4.1 shows the experimental setup of CNC machine AGNI BMV 45T20.

Table 4.1: Specifications of CNC machine AGNO BMV 45 T20

TABLE	UNITS	MEASUREMENT
Clamping area	mm x mm	450 x 900
Max. safe load on table	Kg	600
Traverse		
X-axis	mm	600
Y-axis	mm	450
Z-axis	mm	500
Axis Drive		
Feed rates	mm/min	1-10000
Rapid traverse XYZ axis	m/min	36
Spindle		
Power	Kw	5.5 / 7.5
Speed	rpm	6000
Taper		BT45
Auto Tool Changer		
Number of tools	Nos.	20
Max. tool diameter with adjacent pocket full empty	mm	75/140
Max. tool length	mm	250
Max. tool weight	Kg	8
Tool change time (tool to tool)	Sec	2.5
Accuracy		
Positioning	mm	0.005
Repeatability	mm	0.003
Installation Data		
Machine weight	Kg	4500
Total connected tool	kVA	18
Pneumatic supply	bar	
Power Supply		415V, 50 Hz, 3 Phase

4.2 SPECIFICATION OF WORK PIECE

The work piece material selected for machining on CNC machine for the present work is EN 36 Hardening Steel. EN 36 is 3% nickel, chromium, molybdenum grade. Carburised EN36 gives a hard case with a strong core, whilst retaining a remarkable degree of toughness.

Applications: As a carburising steel grade it is suitable for roller and ball bearings of extra light section, aeroplane and motor crankshafts requiring hard surfaces for roller paths, connecting rods with case-hardened ends, as well as highly stressed gudgeon pins, gears and certain types of collets. Also, Components with large cross section requiring high toughness & score strength such as Gears, Crane Shafts, Heavy Duty Gear shafts in Aircrafts & Truck Construction etc.,

REQUIRMENT FOR CARRYING OUT THIS EXPERIMENT

CNC Machine	:	CNC Machine AGNI BMV 45 T20
Work piece material	:	EN 36 Hardening Steel
Dimensions	:	140 mm Diameter and thickness 24 mm
Quantity	:	2 pieces
Tool Material	:	HSS twist drills carbide coated (10, 12, 15, 18 mm)
Coolant	:	AP Servo 68
Machine	:	Weighing Machine
Roughness Tester	:	Surface Roughness Tester
Software	:	Minitab 17

Table 4.2: Chemical Composition of EN 36

Element	**Carbon**	**Manganese**	**Silicon**	**Nickel**	**Chromium**	**Sulphur & Phosphorous**
Weight (%)	0.12 - 0.18%	0.30 - 0.60%	0.10 - 0.35%	3.00 - 3.75%	0.60 - 1.10%	0.00 -0.05%

Table 4.3: Mechanical Properties of EN 36

Density (g/cm^3)	Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)	Elongation (%)	Hardness (BHN)
7.8	**1100**	**950**	**15**	**341**

High Speed Steel (HSS): The basic composition of High Speed Steel is 18% tungsten (W), 4% Chromium (Cr), 1% vanadium (v), 0.7% carbon (C) and rest Iron (Fe).

The characteristic properties of High Speed Steel are:-

- Excellent hardness.
- High wear resistance.
- Good shock resistance.
- Excellent toughness.
- Fair machinability.
- Good non deforming property.
- Compressive strength.
- High retention of hardness.
- Strength to prevent breakage on the cutting edge.

Figure 4.2: EN 36 Work piece Material & HSS drill bits

The experimental procedure for this present work to be carried out is show in the figure

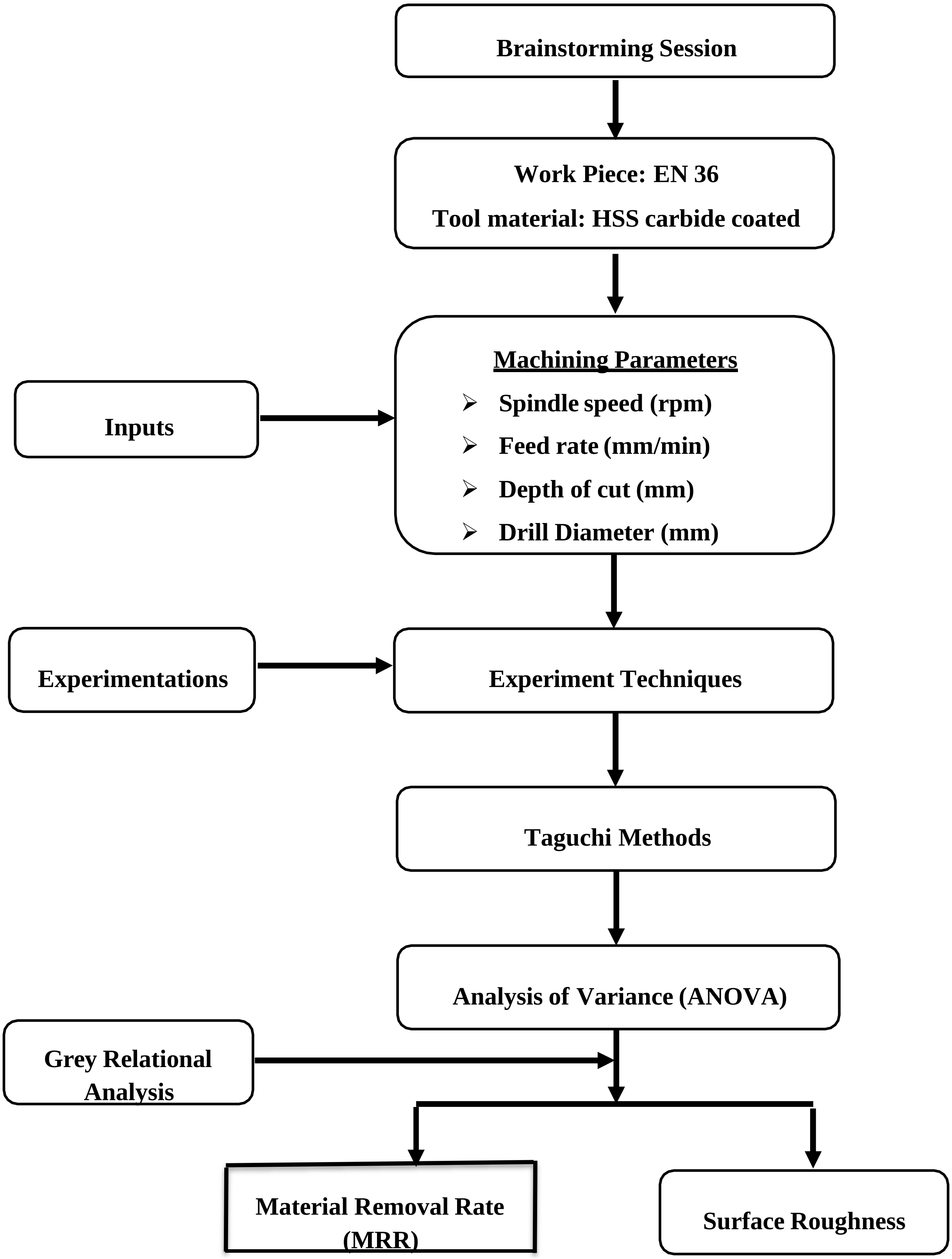

Figure 4.3: Experiment flow chart

4.3 PROCESS PARAMETERS

The process parameters considered for machining are:

1. Spindle speed (rpm)
2. Feed (mm/min)
3. Depth of cut (mm)
4. Drill diameter (mm)

Spindle Speed:

Spindle speed is defined as the angular velocity of the tool bit. It is expressed as revolutions per minute (rpm). Spindle speed has direct influence on surface roughness, since spindle speed and surface roughness are directly proportional to each other. As the spindle increases the surface roughness also increases. Similarly spindle speed has direct influence on material removal rate.

Feed:

Feed is defined as the advance of the tool bit with respect to the work piece. It is expressed as mm/min. The surface roughness increases with increase of feed rate. The longer the feed, which increases the separation between feed marks, leading to an increase in the values of surface roughness. Material Removal Rate is always directly proportional to feed rate since feed is defined as the translating displacement of the cutting edge of the tool along the work surface during the given period of time.

Depth of Cut:

Depth of cut is the thickness of the material that is removed in one cut. It is expressed in mm. Depth of cut is directly proportional to material removal rate. As depth of cut increases the material removal rate increases.

Drill Diameter:

The drill bit is usually a rotary cutting tool, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. The diameter of drill bit is the drill diameter. Eg. Drill diameter 10, 12, 15, 18 mm etc.,

4.4 EXPERIMENTAL PROCEDURE

A series of experiments are planned to conduct to study the effects of various machining parameters on CNC drilling machine. These studies have been undertaken to study the effects of spindle speed, feed rate and depth of cut, drill diameter on Material Removal Rate and Surface roughness with HSS twist drill carbide tool. The specimen is fixed with the help of bolts after checking for flatness using spirit level. HSS tool is fitted to the spindle and fixed. After the setup, machining parameters according to the requirement are given through the parameter window in the display with the help of keyboard. The experimental procedure is given below:-

4.4.1 Identification of Main Function, side effects and failure mode

Main Function: (1) Optimize and Stabilize the Quality Characteristics namely

a. Material Removal Rate
b. Surface Roughness

Side Effects: Since this first trial application no other Quality characteristics will be observed.

Failure Mode: Control Factor Levels are selected so that there will not be any failure during experimentation leading to aborting an experiment.

Before proceeding on to further steps, it is necessary to list down all the factors that are going to affect or influence the drilling process and from those factors one has to identify the control and noise factors. The “Factors” that affect drilling operation on a Drilling machine are listed in the table

Table 4.4: Factors that affect the drilling operation

Control factors	Noise factors
Spindle speed (rpm)	Vibration
Feed rate (mm/min)	Machine Condition
Depth of cut (mm)	Raw Material Vibration
Drill diameter (mm)	Wear & tear

4.4.2 Identify the Objective Function

Objective Function:

(1) MRR ---> LARGER - THE – BETTER

S/N ratio = -10log10 $(1/n\sum^{n}{}_{k=1} ({}^{1}/_{y^2}))$

(2) SR ---> SMALLER - THE – BETTER

S/N ratio = -10 log $\sum^{n}_{k=1} {}^{y^2}/_{n}$

4.4.3 Identifying the Control Factors and their levels

The factors and their levels were decided for conducting the experiment, based on a "brain storming session" that was held with a group of people and also considering the guidelines given in the operator's manual provided by the manufacturer of the machine. The process parameters and their levels are shown in table 4.5

Table 4.5: Process Parameters and their levels

Parameter	Units	Level-1	Level-2	Level-3	Level-4
Spindle Speed (n)	rpm	1000	1500	2000	2500
Feed rate (fr)	mm/min	50	150	200	250
Depth of cut (d)	mm	6	8	12	15
Drill diameter (D)	mm	10	12	15	18

4.4.4 Selection of Orthogonal Array

To select an appropriate orthogonal array for conducting the experiments, the degrees of freedom are to be computed. The same is given below: Degrees of Freedom: 3 for Mean Value and 12= (3x4), three each for the remaining factors Total Degrees of Freedom: 15. The most suitable orthogonal array for experimentation is L16 array as shown below. Therefore, a total sixteen experiments are to be carried out.

4.4.5 Conducting the Matrix Experiment

In accordance with the Orthogonal Array in table 4.6, experiments to be conducted with their factors and their levels as mentioned in table 4.7. Therefore, 16 experiments are to be conducted to account for the variations that may occur due to the noise factors.

Table 4.6: L16 Orthogonal Array

Experiment No.	A	B	C	D
	1	**2**	**3**	**4**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Table 4.7: L16 Orthogonal array with Control factors

Experiment No.	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	1000	50	6	10
2	1000	100	9	12
3	1000	150	12	15
4	1000	200	15	18
5	1500	50	9	15
6	1500	100	6	18
7	1500	150	15	10
8	1500	200	12	12
9	2000	50	12	18
10	2000	100	15	15
11	2000	150	6	12
12	2000	200	9	10
13	2500	50	15	12
14	2500	100	12	10
15	2500	150	9	18
16	2500	200	6	15

After the L16 orthogonal array arrangement, the experiment is carried out and the observations for Material Removal Rate and Surface Roughness are noted. The observation data is used for calculating the Signal to Noise ration values (S/N) based on Taguchi Method and ANOVA is carried out for determining the degree of difference or similarity between two or more groups of data. Finally, Grey technique is carried out for converting the multi-objective function to single object function. The results for the experiments done are shown in the next chapter in detail.

5. RESULTS AND DISCUSSIONS

In this chapter all the results obtained from the experimentation process from the machining of CNC Drilling are per the Taguchi's L16 orthogonal array are given. A series of experiments are conducted on the material EN 36 with different drill diameters of HSS carbide coated tool. The components after machining are tested for surface roughness and material removal rate through their respective procedures. Then the S/N ratios are obtained for MRR at larger-the-better and Surface Roughness at smaller-the-better. All the results are shown below. The Minitab software tool is used to calculate Taguchi analysis and ANOVA. All the graphs are also obtained from the software. All the experimental results of the output parameters and their signal to noise ratios are given below in table 5.1 and 5.2.

Table 5.1: Experimental results of output responses.

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia	MRR (mm^3/min)	Average R_a	Average R_q	Average R_z
1	1000	50	6	10	471	7.33	9.11	24.36
2	1000	100	9	12	1017	4.97	6.03	18.32
3	1000	150	12	15	2120	4.96	6.53	20.14
4	1000	200	15	18	2200	3.93	4.83	14.15
5	1500	50	9	15	1300	3.80	4.79	13.73
6	1500	100	6	18	1526	5.13	5.99	17.23
7	1500	150	15	10	1178	4.25	5.47	14.67
8	1500	200	12	12	1200	4.89	5.94	18.04
9	2000	50	12	18	3052	6.06	7.25	19.85
10	2000	100	15	15	1900	3.76	4.93	14.97
11	2000	150	6	12	678	7.25	8.61	24.00
12	2000	200	9	10	707	6.39	7.64	20.50
13	2500	50	15	12	1696	3.92	5.05	14.72
14	2500	100	12	10	800	4.73	5.95	15.48
15	2500	150	9	18	2000	3.90	4.89	12.90
16	2500	200	6	15	1060	5.68	6.96	19.97

Table 5.2: S/N ratios of process responses

Runs	S/N (MRR)	S/N (R_a)	S/N (R_q)	S/N (R_z)
1	53.4604	-17.3021	-19.1904	-27.7335
2	60.1495	-13.9271	-15.6063	-25.2585
3	66.5247	-13.9096	-16.2983	-26.0812
4	66.8485	-11.8879	-13.6789	-23.0151
5	62.2789	-11.5957	-13.6067	-22.7534
6	63.6713	-14.2023	-15.5485	-24.7257
7	61.4192	-12.5678	-14.7597	-23.3286
8	61.5836	-13.7862	-15.4757	-25.1247
9	69.6917	-15.6495	-17.2068	-25.9552
10	65.5751	-11.5038	-13.8569	-23.5044
11	56.6277	-17.2068	-18.7001	-27.6042
12	56.9822	-16.1100	-17.6619	-26.2351
13	64.5865	-11.8657	-14.0658	-23.3582
14	58.0618	-13.4972	-15.4903	-23.7954
15	66.0206	-11.8213	-13.7862	-22.2118
16	60.5041	-15.0870	-16.8522	-26.0076

5.1 S/N RATIO AND ANOVA ANALYSIS FOR MRR

5.1.1 Signal to noise ratios for MRR

Table 5.3: Response S/N ratios for MRR

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Diameter
1	61.75	62.50	58.57	57.48
2	62.24	61.86	61.36	60.74
3	62.22	**62.65**	63.97	63.72
4	**62.29**	61.48	**64.61**	**66.56**
DELTA	0.55	1.17	6.04	9.08
RANK	4	3	2	1

The optimal parameters from the table 5.3 by Taguchi design for MRR are spindle speed = 2500 rpm, feed rate = 150 mm/min, depth of cut = 15 mm and drill diameter = 18 mm. The corresponding levels and optimal process parameters are shown in Table 5.4

Table 5.4: Optimum parameter levels MRR

Parameters	Runs	Runs Description	Units
Spindle Speed	A_4	2500	rpm
Feed rate	B_3	150	mm/min
Depth of cut	C_4	15	mm
Drill Diameter	D_4	18	mm

5.1.2 Predicted MRR

Predicted S/N Ratio = Y+ (A_4-Y) + (B_3-Y) + (C_4-Y) + (D_4-Y)

Where, Y = Average of S/N Ratio values for MRR i.e.

Y=SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9+SN10+SN11+SN12+SN13+SN14+SN15+SN16)/16

Y = 62.12

A_4, B_3, C_4, D4 values are taken from table 5.3

Predicted S/N Ratio =62.12+ (62.29-62.12) + (62.65-62.12) + (64.61-62.12) + (66.56-62.12) = 69.75. (Higher the better)

For higher –the - better

S/N Ratio= -10 log (1/ (MSD)) = -10 log (1/ (MRR) ^{2})

MRR = 3072.56 mm^3/min (predicted value)

From the parameters, it is clear that the responses obtained for optimum conditions are not in the orthogonal array values, so to find the response parameter values for this case a confirmatory test has to be conducted and the values obtained from the test are to be compared with the predicted values. It is shown in the table 5.5.

Table 5.5: Results of the confirmation experiment for MRR

Confirmation experiment for MRR (mm^3/min)		
Level	**Predicted value**	**Experimental results**
A_4, B_3, C_4, D_4	3072.56	3052

The Fig 5.1 shows the Taguchi optimal parameters for MRR. It shows the affect of each parameter on the response MRR. First, the S/N ratio mean is calculated for each level of each parameter and then a plot is generated as shown below to show at which level of each parameter the mean of S/N ratio is larger. The level at which the S/N ratio is larger would give the signal for the required response, MRR in this case. That particular level of each parameter is taken as the optimal parameter for MRR as per Taguchi optimization.

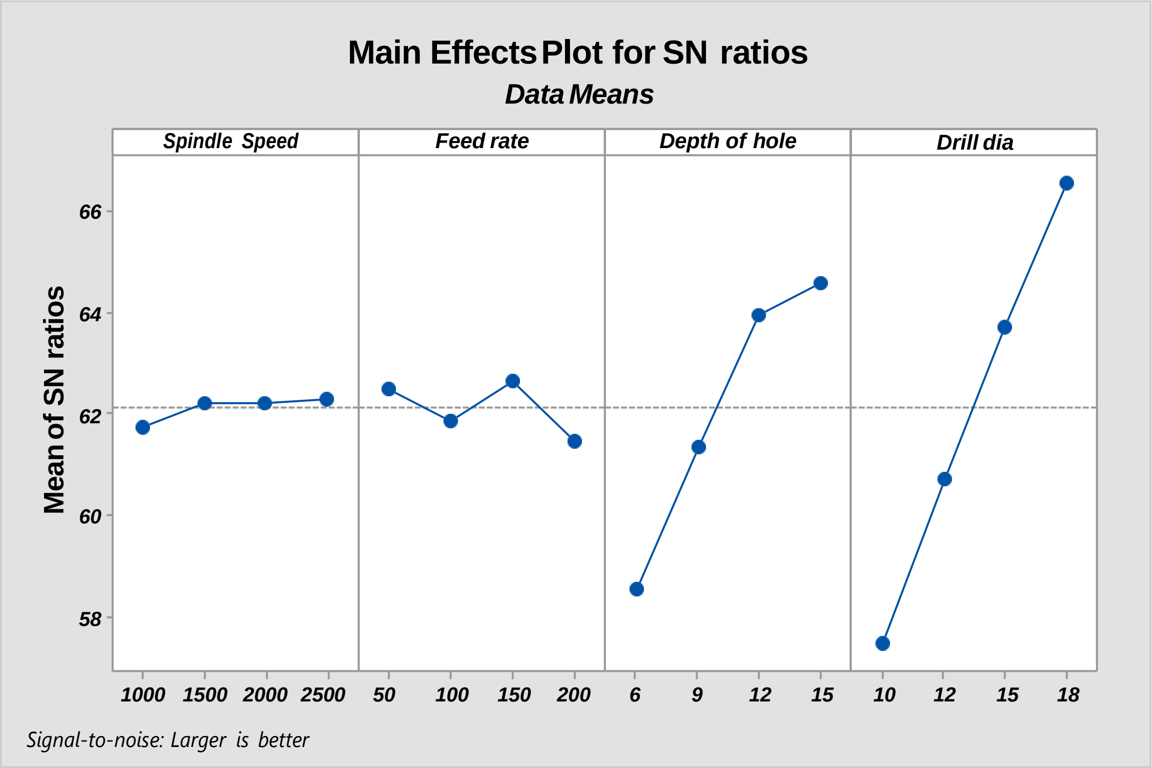

Figure 5.1: Main effects plot for SN ratios (MRR)

5.1.3 Analysis of Variance for MRR:

Table 5.6: ANOVA Results for MRR

Source	DF	Adj. SS	Adj.MS	F-value	P-value	% Contribution
Spindle Speed	3	170448	56816	0.67	0.627	2.48%
Feed	3	309140	103047	1.21	0.440	4.47%
Depth of cut	3	2025423	675141	7.91	0.062	29.27%
Drill Diameter	3	4409874	1469958	17.23	0.021	63.76%
Error	3	255933	85311			
Total	15	7170816				

S= 292.080, R-sq = 96.43%, R-sq (adj) = 82.15%

From the ANOVA table 5.6, the most significant factors that affect MRR are Drill diameter (mm), followed by Depth of cut (mm), feed (mm/min) and Spindle Speed (rpm), the percentage contribution of Drill diameter is 63.76%.

5.2 S/N RATIO AND ANOVA ANALYSIS FOR R_a

5.2.1 Signal to noise ratios for R_a

Table 5.7: Response S/N ratios for R_a

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	-14.26	-14.10	-15.95	-14.87
2	**-13.04**	**-13.28**	-13.36	-14.20
3	-15.12	-13.88	-14.21	**-13.02**
4	-13.07	-14.22	**-11.96**	-13.39
DELTA	2.08	0.94	3.99	1.85
RANK	2	4	1	3

The optimal parameters from the table 5.7 by Taguchi design for R_a are Spindle speed=1500 rpm, Feed rate = 100 mm/min, Depth of cut = 15 mm and Drill diameter = 15 mm. The corresponding levels and optimal process parameters are shown in Table 5.8

Table 5.8: Optimum parameter levels R_a

Parameters	Runs	Runs Description	Units
Spindle Speed	A_2	1500	rpm
Feed rate	B_2	100	mm/min
Depth of cut	C_4	15	mm
Drill Diameter	D_3	15	mm

5.2.2 Predicted Surface Roughness (R_a)

Predicted S/N Ratio = Y+ (A_2-Y) + (B_2-Y) + (C4-Y) + (D_3-Y)

Where, Y = Average of S/N Ratio values for Surface Roughness

Y=SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9+SN10+SN11+SN12+SN13+SN14+SN15+SN16)/16

Y = -13.87

A_2, B_2, C_4, D_3 values are taken from table 5.3

Predicted S/N Ratio:

= -13.87+ (**-13.04** - (-13.87)) + (**-13.28** - (-13.87)) + (**-11.96** - (-13.87)) + (**-13.02** - (-13.87))

Predicted S/N Ratio = -9.69 (Smaller the better)

For smaller the better (S/N Ratio= -10 log (MSD))

$-9.69 = -10 \log ((R_a)^2)$

R_a = 3.051 µm (predicted value)

From the parameters it is clear that the responses obtained for optimum conditions are not in the orthogonal array values, so to find the response parameter values for this case a confirmatory test has to be conducted and the values obtained from the test are to be compared with the predicted values. It is shown in the table 5.9.

Table 5.9: Results of the confirmation experiment for Surface Roughness

Confirmation experiment for R_a (µm)		
Level	**Predicted value**	**Experimental results**
A_2, B_2, C_4, D_3	3.051	3.35

The Fig 5.2 shows the Taguchi optimal parameters for Ra. It shows that affect of each parameter on the response R_a. First, the S/N ratio mean is calculated for each level of each parameter and then a plot is generated as shown below to show at which level of each parameter the mean of S/N ratio is smaller. The level at which the S/N ratio is smaller would give the smaller signal for the required response, R_a in this case. That particular level of each parameter is taken as the optimal parameter for R_a as per Taguchi optimization.

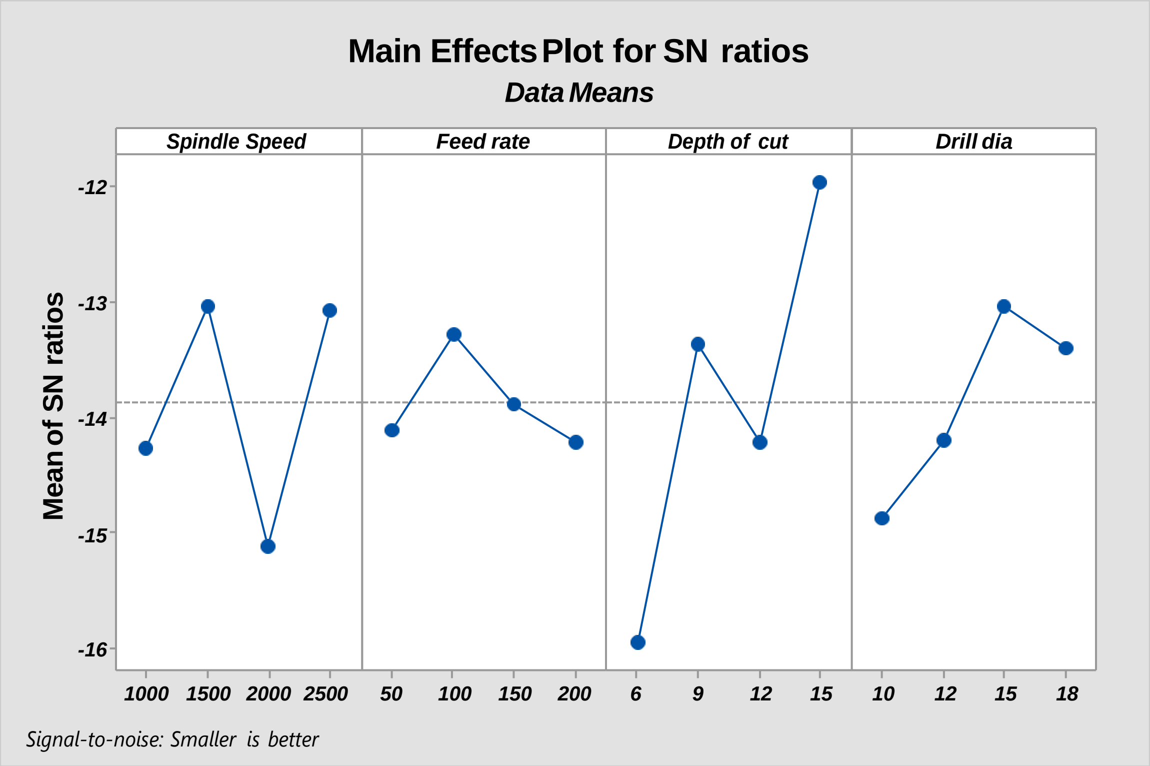

Figure 5.2: Main effects plot for SN ratios (R_a)

5.2.3 Analysis of Variance for R_a:

Table 5.10: ANOVA Results for R_a

Source	DF	Adj. SS	Adj.MS	F-value	P-value	% Contribution
Spindle Speed	3	5.0050	1.66832	20.97	0.016	23.97%
Feed	3	0.9791	0.32636	4.10	0.138	4.69%
Depth of cut	3	11.8148	3.93827	49.51	0.005	56.59%
Drill Diameter	3	3.0814	1.02714	12.91	0.032	14.76%
Error	3	0.2386	0.07954			
Total	15	21.1189				

S= 0.282028, R-sq = 98.87%, R-sq(adj) = 94.35%, R-sq(pred)= 67.86%

From the ANOVA table 5.10, the most significant factors that affect the Surface roughness (R_a) are Depth of cut (mm), followed by Spindle speed (rpm), Drill diameter (mm) and Feed (mm/min). The percentage contribution of Depth of cut is 56.59%

5.3 S/N RATIO AND ANOVA ANALYSIS FOR R_q

5.3.1 Signal to noise ratios for R_q

Table 5.11: Response S/N ratios for R_q

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	-16.19	-16.02	-17.57	-16.78
2	**-14.85**	**-15.13**	-15.17	-15.96
3	-16.86	-15.89	-16.12	-15.15
4	-15.05	-15.92	**-14.09**	**-15.06**
DELTA	2.01	0.89	3.48	1.72
RANK	2	4	1	3

The optimal parameters from the table 5.11 by Taguchi design for R_q are Spindle Speed = 1500 rpm, Feed rate = 100 mm/min, Depth of cut = 15 mm and Drill diameter = 18 mm. The corresponding levels and optimal process parameters are shown in Table 5.12

Table 5.12: Optimum parameter levels R_q

Parameters	Runs	Runs Description	Units
Spindle Speed	A_2	1500	rpm
Feed rate	B_2	100	mm/min
Depth of cut	C_4	15	mm
Drill Diameter	D_4	18	mm

5.3.2 Predicted Surface Roughness (R_q)

Predicted S/N Ratio = $Y + (A_2 - Y) + (B_2 - Y) + (C_4 - Y) + (D_4 - Y)$

Where, Y = Average of S/N Ratio values for Surface Roughness

i.e.

Y =

SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9+SN10+SN11+SN12+SN13+SN14+SN15+SN16)/16

Y = -15.74

A_2, B_2, C_4, D_4 values are taken from table 5.3

Predicted S/N Ratio:

= -15.74+ (**-14.85** – (-15.74)) + (**-15.13** – (-15.74)) + (**-14.09** – (-15.74)) + (**-15.06** – (-15.74))

Predicted S/N Ratio = -11.91 (Smaller the better)

For smaller –the – better

S/N Ratio= -10 log (MSD)

$-11.91 = -10 \log ((R_q)^2)$

R_q = 3.94 µm (predicted value)

From the parameters it is clear that the responses obtained for optimum conditions are not in the orthogonal array values, so to find the response parameter values for this case a confirmatory test has to be conducted and the values obtained from the test are to be compared with the predicted values. It is shown in the table 5.13.

Table 5.13: Results of the confirmation experiment for Surface Roughness

Confirmation experiment for R_q (µm)		
Level	**Predicted value**	**Experimental results**
A_2, B_2, C_4, D_4	3.94	4.25

The Fig 5.3 shows the Taguchi optimal parameters for R_q. It shows that affect of each parameter on the response R_q. First, the S/N ratio mean is calculated for each level of each parameter and then a plot is generated as shown below to show at which level of each parameter the mean of S/N ratio is smaller. The level at which the S/N ratio is smaller would give the smaller signal for the required response, R_q in this case. That particular level of each parameter is taken as the optimal parameter for R_q as per Taguchi optimization.

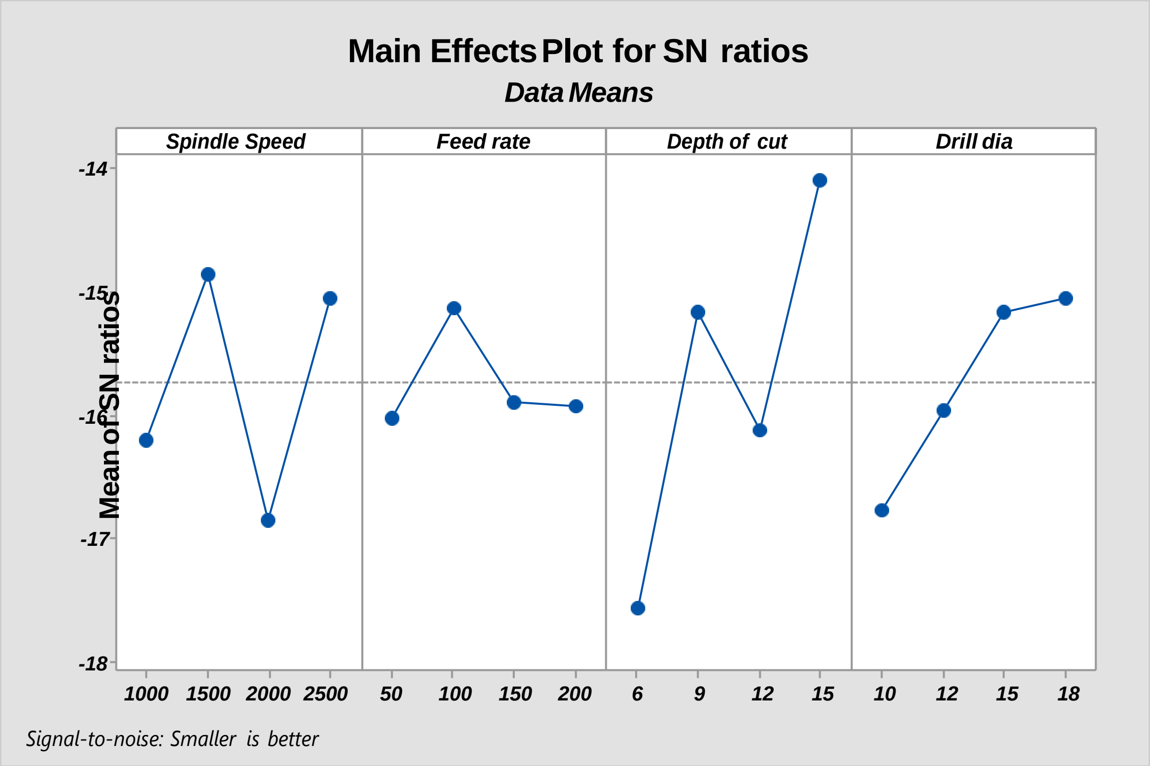

Figure 5.3: Main effects plot for SN ratios (R_q)

5.3.3 Analysis of Variance for R_q:

Table 5.14: ANOVA Results for R_q

Source	DF	Adj. SS	Adj.MS	F-value	P-value	% Contribution
Spindle Speed	3	6.6333	2.2111	21.44	0.016	24.53%
Feed	3	1.5592	0.5197	5.04	0.108	7.76%
Depth of cut	3	14.3996	4.7999	46.55	0.005	53.24%
Drill Diameter	3	4.4528	1.4843	14.40	0.028	16.47%
Error	3	0.3093	0.1031			
Total	15	27.3542				

S= 0.321102, R-sq = 98.87%, R-sq (adj) = 94.35%, R-sq(pred) =67.84%

From the ANOVA table 5.14, the most significant factors that affect R_q are Depth of cut (mm) followed by Spindle Speed (rpm), Drill Diameter (mm) and feed (mm/min). The percentage contribution of Depth of cut is 53.24%

5.4 S/N RATIO AND ANOVA ANALYSIS FOR R_z

5.4.1 Signal to noise ratios for R_z

Table 5.15: Response S/N ratios for R_z

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	-25.52	-24.95	-26.52	-25.27
2	-23.98	**-24.32**	-24.11	-25.34
3	-25.82	-24.81	-25.24	-24.59
4	**-23.84**	-25.10	**-23.30**	**-23.98**
DELTA	1.98	0.77	3.22	1.36
RANK	2	4	1	3

The optimal parameters from the table 5.15 by Taguchi design for R_z are Spindle speed = 2500 rpm, Feed rate = 100 mm/min, Depth of Cut = 15 mm and Drill Diameter = 18 mm. The corresponding levels and optimal process parameters are shown in Table 5.16

Table 5.16: Optimum parameter levels R_z

Parameters	Runs	Runs Description	Units
Spindle Speed	A_4	2500	rpm
Feed rate	B_2	100	mm/min
Depth of cut	C_4	15	mm
Drill Diameter	D_4	18	mm

5.4.2 Predicted Surface Roughness (R_z)

Predicted S/N Ratio = Y+ (A_4-Y) + (B_2-Y) + (C_4-Y) + (D_4-Y)

Where, Y = Average of S/N Ratio values for Surface Roughness

i.e.

Y = SN1+SN2+SN3+SN4+SN5+SN6+SN7+SN8+SN9+SN10+SN11+SN12+SN13+SN14+SN15+SN16)/16

Y = -24.79

A_4, B_2, C_4, D_4 values are taken from table 5.3

Predicted S/N Ratio:

=-24.79+ (**-23.84** – (-24.79) + (**-24.32** – (-24.79) + (**-23.30** – (-24.79) + (**-23.98** – (-24.79)

Predicted S/N Ratio =-21.07 (Smaller the better)

For smaller –the – better

S/N Ratio= -10 log (MSD)

$-21.07= -10 \log ((R_z)^2)$

$R_z = 11.31$ µm (predicted value)

From the parameters it is clear that the responses obtained for optimum conditions are not in the orthogonal array values, so to find the response parameter values for this case a confirmatory test has to be conducted and the values obtained from the test are to be compared with the predicted values. It is shown in the table 5.17.

Table 5.17: Results of the confirmation experiment for Surface Roughness

Confirmation experiment for R_z (µm)		
Level	**Predicted value**	**Experimental results**
A_4, B_2, C_4, D_4	11.31	12.90

The Fig 5.4 shows the Taguchi optimal parameters for R_z. It shows that affect of each parameter on the response R_z. First, the S/N ratio mean is calculated for each level of each parameter and then a plot is generated as shown below to show at which level of each parameter the mean of S/N ratio is smaller. The level at which the S/N ratio is smaller would give the smaller signal for the required response, R_z in this case. That particular level of each parameter is taken as the optimal parameter for R_z as per Taguchi optimization.

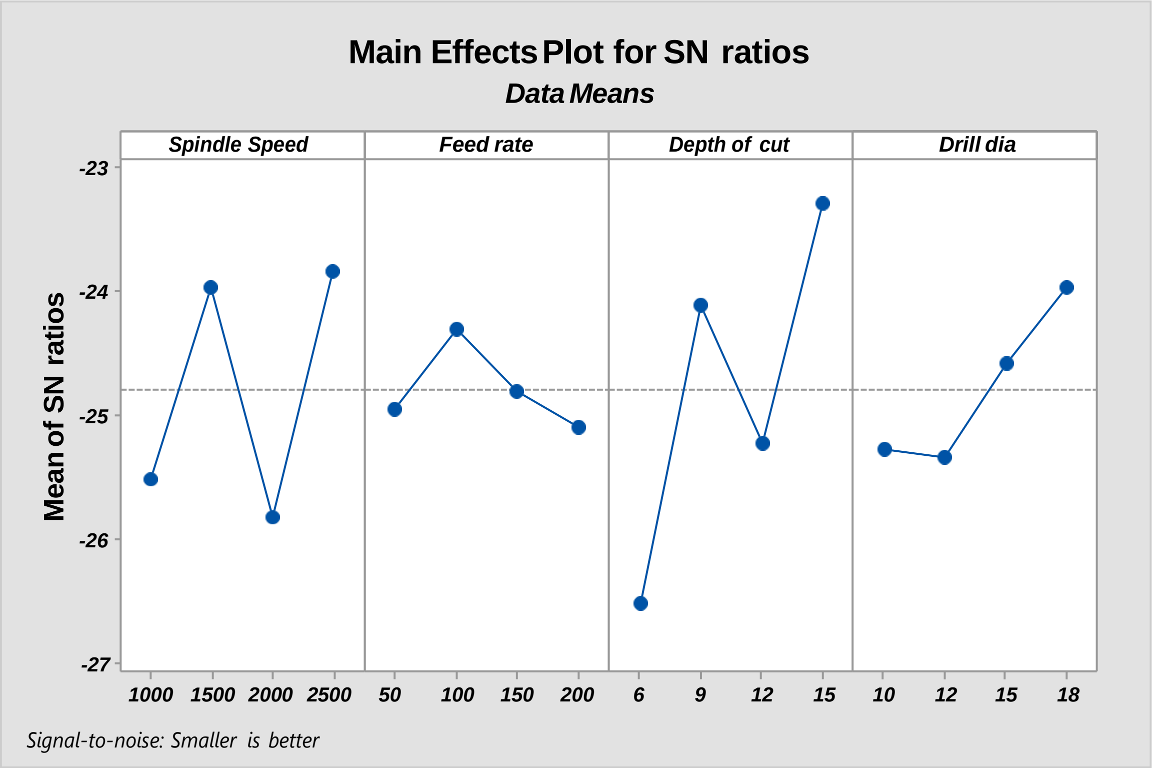

Figure 5.4: Main effects plot for SN ratios (R_z)

5.4.3 Analysis of Variance for R_z:

Table 5.18: ANOVA Results for R_z

Source	DF	Adj. SS	Adj.MS	F-value	P-value	% Contribution
Spindle Speed	3	55.310	18.437	11.43	0.038	29.84%
Feed	3	7.695	2.565	1.59	0.356	4.15%
Depth of cut	3	101.215	33.738	20.92	0.016	54.61%
Drill Diameter	3	21.121	7.040	4.37	0.129	11.40%
Error	3	4.838	1.613			
Total	15	190.180				

S= 1.26989, R-sq = 97.46%, R-sq (adj) = 87.28%, R-sq(pred) =27.64%

From the ANOVA table 5.18, the most significant factors that affect R_z are Depth of cut (mm) followed by Spindle speed (rpm), drill diameter (mm) and feed (mm/min). The percentage contribution of Depth of cut is 54.61%

5.5 GREY RELATIONAL ANALYSIS

Taguchi analysis method can optimize a single objective function; it cannot solve multi-objective optimization problem. So, MRR and Surface roughness can be optimized individually by using this Taguchi technique. But it may so happen that, the optimal setting for a response variable cannot ensure other response variables within acceptable limits. So, one should go for such an optimal parameter setting so that all the objectives should fulfill simultaneously; (maximum MRR, and minimum Surface roughness).These will be achieved using grey based Taguchi method as discussed below. This method can convert several objective functions into an equivalent single objective function (representative of all desired response characteristics of the product/process), which would be maximized next. Calculations are carried as explained in the chapter 4. Table 5.19 shows the process responses of experiment trails.

Table 5.19: Process Responses

Exp. No	MRR mm^3/min	Average Surface roughness R_a (μm)	Root mean square roughness R_q (μm)	Ten point mean roughness R_z (μm)
1	471	7.33	9.11	24.36
2	1017	4.97	6.03	18.32
3	2120	4.96	6.53	20.14
4	2200	3.93	4.83	14.15
5	1300	3.8	4.79	13.73
6	1526	5.13	5.99	17.23
7	1178	4.25	5.47	14.67
8	1200	4.89	5.94	18.04
9	3052	6.06	7.25	19.85
10	1900	3.76	4.93	14.97
11	678	7.25	8.61	24.00
12	707	6.39	7.64	20.50
13	1696	3.92	5.05	14.72
14	800	4.73	5.95	15.48
15	2000	3.9	4.89	12.90
16	1060	5.68	6.96	19.97

5.5.1 Grey Relational Analysis

Step 1: Pre-processing data: The obtained process responses are pre-processes in the first step as explained. Table 5.20 shows the Pre-processing data for each individual response. Using the formula discussed in the chapter 4

Table 5.20 Pre-processing data

Exp. No	MRR mm^3/min	Average Surface roughness R_a (μm)	Root mean square roughness R_q (μm)	Ten point mean roughness R_z (μm)
1	0.0000	0.0000	0.0000	0.0000
2	0.2117	0.6611	0.7130	0.5271
3	0.6387	0.6639	0.5972	0.3682
4	0.6699	0.9524	0.9907	0.8909
5	0.3212	0.9888	1.0000	0.9276
6	0.4088	0.6162	0.7222	0.6222
7	0.2737	0.8627	0.8426	0.8455
8	0.2824	0.6835	0.7338	0.5515
9	1.0000	0.3557	0.4306	0.3935
10	0.5537	1.0000	0.9676	0.8194
11	0.0803	0.0224	0.1157	0.0314
12	0.0912	0.2633	0.3403	0.3368
13	0.4745	0.9552	0.9398	0.8412
14	0.1275	0.7283	0.7315	0.7749
15	0.5924	0.9608	0.9769	1.0000
16	0.2281	0.4622	0.4977	0.3831

Step 2: Sequencing deviation (Δ_{0i}): Deviation sequencing is calculated for the obtained pre-processing data by considering ideal value 1. Results of sequencing deviation are shown in the Table 5.21.

Table 5.21 Sequencing deviation (Δ_{0i}) Ideal Value=l

Exp. No	MRR mm^3/min	Average Surface roughness R_a (µm)	Root mean square roughness R_q (µm)	Ten point mean roughness R_z (µm)
1	1.0000	1.0000	1.0000	1.0000
2	0.7883	0.3389	0.2870	0.4729
3	0.3613	0.3361	0.4028	0.6318
4	0.3301	0.0476	0.0093	0.1091
5	0.6788	0.0112	0.0000	0.0724
6	0.5912	0.3838	0.2778	0.3778
7	0.7263	0.1373	0.1574	0.1545
8	0.7176	0.3165	0.2662	0.4485
9	0.0000	0.6443	0.5694	0.6065
10	0.4463	0.0000	0.0324	0.1806
11	0.9197	0.9776	0.8843	0.9686
12	0.9088	0.7367	0.6597	0.6632
13	0.5255	0.0448	0.0602	0.1588
14	0.8725	0.2717	0.2685	0.2251
15	0.4076	0.0392	0.0231	0.0000
16	0.7719	0.5378	0.5023	0.6169

Step 3: Grey relational coefficient ($\xi_i(k)$): In the next step coefficient $\xi_i$is calculated for all the obtained deviational sequencing data individually, Grey relational coefficient ξi(k) is calculated. Grey Relational Coefficients are shown in the Table 5.22.

Table 5.22: Grey relational coefficient ($\xi_i(k)$)

Exp. No	MRR mm^3/min	Average Surface roughness R_a (µm)	Root mean square roughness R_q (µm)	Ten point mean roughness R_z (µm)
1	0.333333	0.333333	0.333333	0.333333
2	0.388104	0.595993	0.635294	0.513901
3	0.580522	0.597990	0.553846	0.441789
4	0.602334	0.913043	0.981818	0.820917
5	0.424158	0.978082	1.000000	0.873476
6	0.458199	0.565769	0.642857	0.569583
7	0.407741	0.784615	0.760563	0.764000
8	0.410660	0.612350	0.652568	0.527139
9	1.000000	0.436965	0.467532	0.451893
10	0.528352	1.000000	0.939130	0.734615
11	0.352186	0.338389	0.361204	0.340463
12	0.354923	0.404304	0.431138	0.429857
13	0.487551	0.917738	0.892562	0.758940
14	0.364291	0.647913	0.650602	0.689531
15	0.550907	0.927273	0.955752	1.000000
16	0.393116	0.481781	0.498845	0.447656

Step 4: Grey Relational Grade, from the obtained coefficients in table 5.22, grey relational grade is calculated. Table 5.23 shows the Grey relational Grade values.

Table 5.23: Grey Relational Grade

Experiment Number	**Grey Relational Grade**
1	0.333333
2	0.533323
3	0.543537
4	0.829528
5	0.818929
6	0.559102
7	0.679230
8	0.550679
9	0.589097
10	0.800524
11	0.348060
12	0.405055
13	0.764198
14	0.588084
15	0.858483
16	0.455350

Step 5: Taguchi for Grey Relational Grade: In the final step the obtained Grey relational grade has been analyzed by using Taguchi, AVOVA to obtain the optimal process parameter level.

Table 5.24: Response Table for Signal to Noise Ratios

Level	**Spindle Speed**	**Feed**	**Depth of Cut**	**Drill Diameter**
1	-5.480	-4.552	-7.648	-6.341
2	-3.832	**-4.264**	-4.093	-5.536
3	-5.886	-4.787	-4.921	-3.949
4	**-3.776**	-5.372	**-2.313**	**-3.149**
Delta	2.110	1.109	5.335	3.192
Rank	3	4	1	2

Optimal parameters from the table 5.24, by Taguchi design for Grey relational grade are Spindle speed = 2500 rpm, feed = 100 mm/min, Depth of cut = 15 mm and Drill diameter = 18 mm. The corresponding levels and optimal process parameters are shown in Table 5.25.

Table 5.25: Optimal process parameters for MRR and Surface roughness

Parameters	**Level**	**Level Description**	**Units**
Spindle speed	A_4	2500	**rpm**
Feed	B_2	100	**mm/min**
Depth of Cut	C_4	15	**mm**
Drill diameter	D_4	18	**mm**

5.5.2 Analysis of variance for Grey Relational Grade

From the ANOVA table 5.26, the most significant factors that affect the both MRR and Surface roughness are in Depth of cut, Drill Diameter, Spindle speed and feed respectively.

Table 5.26: Results of ANOVA for Grey Relational Grade

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Spindle speed	3	0.05128	0.017094	2.26	0.260	12.43%
Feed	3	0.01079	0.003598	0.48	0.721	2.64%
Depth of Cut	3	0.25293	0.084310	11.17	0.039	61.47%
Drill diameter	3	0.10853	0.036178	4.79	0.115	26.36%
Error	3	0.02265	0.007550			
Total	15	0.44619				

S = 0.0868882 R-Sq = 94.92% R-Sq (adj) = 74.62%

Based on the percentage of contribution it can be said that Depth of cut has more affect on MRR and Surface roughness. The percentage contribution of Depth of Cut is 61.47%. The following graph below shows the Taguchi optimal parameters for MRR and Surface roughness. The graph shows the effect of each parameter on the process response.

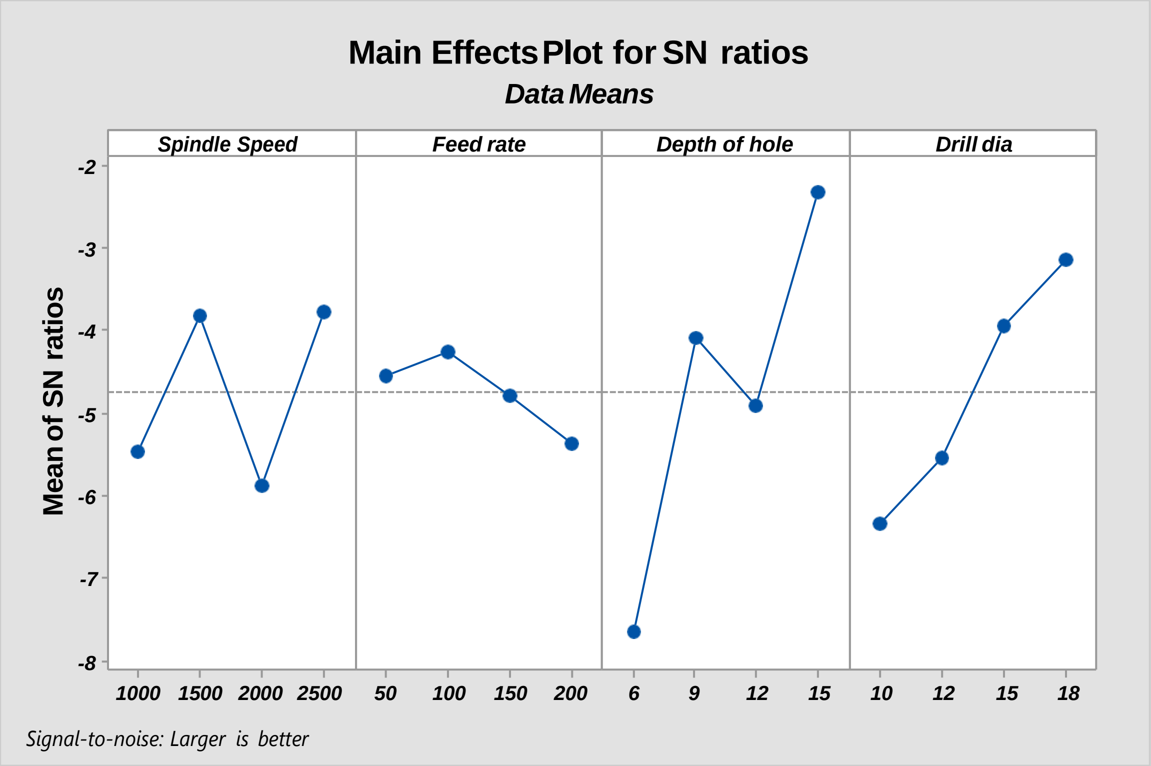

Figure 5.5: Main effect plot for Grey relational grade (MRR, R_a, R_q, R_z)

5.6 DETERMINATION OF OPTIMAL CONDITIONS

The optimal conditions are those which provide the best performance based on the data obtained from the experiment. In this case, the condition for significant design parameters based on main effect are selected by making use of Taguchi, ANOVA and Grey relational analysis. The optimal conditions are determined as:

1. **Material Removal Rate (MRR)**
    - a. Spindle Speed - 2500 rpm
    - b. Feed rate - 150 mm/min
    - c. Depth of Cut - 15 mm
    - d. Drill Diameter - 18 mm
2. **Average Surface Roughness (R_a)**
    - a. Spindle Speed - 1500 rpm
    - b. Feed rate - 100 mm/min
    - c. Depth of Cut - 15 mm
    - d. Drill Diameter - 15 mm
3. **Root Mean Square Surface Roughness (R_q)**
    - a. Spindle Speed - 1500 rpm
    - b. Feed rate - 100 mm/min
    - c. Depth of Cut - 15 mm
    - d. Drill Diameter - 18 mm
4. **Ten Point Mean Surface Roughness (R_z)**
    - a. Spindle Speed 2500 rpm
    - b. Feed rate - 100 mm/min
    - c. Depth of Cut - 15 mm
    - d. Drill Diameter - 18 mm
5. **MRR and Surface Roughness (R_a, R_q & R_z)**
    - a. Spindle Speed - 2500 rpm
    - b. Feed rate - 100 mm/min
    - c. Depth of Cut - 15 mm
    - d. Drill Diameter - 18 mm

6. CONCLUSION

Based on the results obtained and discussion made in the earlier chapters the following conclusions are drawn:

- This study aimed to investigate the drilling performance of EN36 hardening steel using CNC drilling machine with a Carbide-coated HSS twist drill. Various drilling parameters were considered, and the resulting surface roughness and MRR values were recorded under different cutting conditions.

- Grey relational analysis in the Taguchi method was used to optimize the multi-response problems associated with drilling, and the prominent factors affecting the drilling process were identified.

- The analysis showed that the spindle speed, feed rate, depth of cut and drill diameters were the most significant factors, with the drill diameter having the greatest influence on the process.

- The study revealed that the optimum performance was achieved using a Carbide-coated HSS twist drill with a largest drill diameter of 18mm (D4), low feed of 100 mm/min (B2), higher depth of cut of 15mm(C4) and a higher spindle speed of 2500rpm(A4).

- Using the grey grade value, based on Taguchi, Anova method, The results showed that the Depth Of Cut (61.47%) influenced the most on drilling EN36 hardening steel, followed by Drill Diameter (26.36%), Spindle Speed (12.43%) , and the least influencing factor is Feed Rate (2.64%).

- The study demonstrates the usefulness of grey relational analysis in the Taguchi method as a tool for predicting drilling performance and optimizing drilling parameters, without the need for complicated mathematical theories or statistical expertise.

FUTURE SCOPE

The present work was done to find out the parameters combination which will result in the optimum Surface Roughness and Material Removal Rate when a specific work piece is machined using a CNC Machine. The parameters considered were Speed, Feed and Depth of Cut Drill diameter. Further in each parameter four levels were taken, the Design of Experiments was Taguchi Method with L16 Orthogonal array is selected followed by ANOVA and Grey Relational Analysis for Multi-optimization.

In future, we suggest the work can be improved by using different input parameters along with the Optimization techniques such as Genetic Algorithm or Response Surface Methodology.

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