

Effects of Cutting Parameters on Temperature, MRR, Shear Angle & Surface Roughness & Optimizing using Taguchi Technique

Report submitted for the project

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

BACHELOR OF TECHNOLOGY IN MECHANICAL ENGINEERING

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ABSTRACT

The cutting tool plays a significant role in the machining process of a part in the production. It not only performs the cutting action but also helps get the required surface finish and accuracy. To perform these tasks the tool has to be strong enough to withstand wear-resistance and serve for a prolonged period to produce more components with the same accuracy. Machining is essential in the metal manufacturing process to achieve near-net shape, good dimensional accuracy, and aesthetic requirements.

While machining a substance, it is desired to obtain maximum material removal rate and a good surface finish (i.e., lowest surface roughness) without generating high temperatures (as they lead to sour surface finish and tool failure). While machining hard materials like SS 304 steel, inevitable consequences are arising due to unique properties of the material like low specific heat, tendency to strain harden etc.,

This study mainly concentrates on comparing various effects of cutting parameters like speed, feed, and depth of cut on SS 304 stainless steel under dry and wet conditions. The observations temperature, Surface Roughness, Shear Angle, Material Removal Rate, chip thickness ratio was made. These output parameters were made into single parameter using TOPSIS method and optimized the cutting parameters using Taguchi Technique using Minitab software.

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CHAPTER 1. INTRODUCTION

In this chapter, concept of turning is defined. The adjustable cutting parameters for the turning process that affect the workpiece output.

1.1 TURNING OPERATION

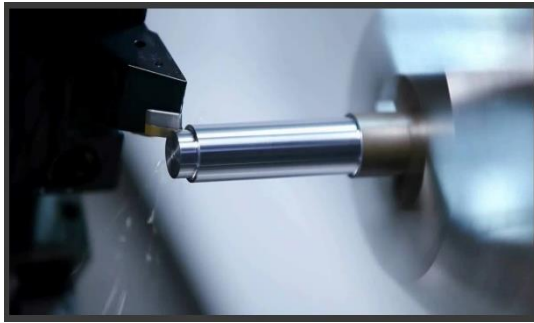


Figure 1. 1: Turning Operation

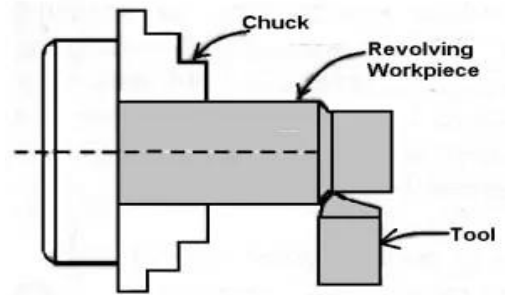


Figure 1. 2: Turning Operation in 2-D View

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, workpiece, fixture, and cutting tool. The workpiece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cutting tool feeds into the rotating workpiece and cuts away material in the form of small chips to create the desired shape.

Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed.

1.2 ADJUSTABLE CUTTING PARAMETERS IN TURNING

The three primary factors in any essential turning operation are speed, feed, and depth of cut. Other factors such as the kind of material and type of tool have a significant influence, of course, but these three are the ones the operator can change by adjusting the controls right on the machine.

1.2.1 Speed:

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm), it defines the speed of rotation. But, the vital feature for a particular turning operation is the surface speed or the speed at which the work piece material is moving past the cutting tool. The product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same

$$V = \pi DN/1000$$

Here, v is the cutting speed in turning in m/min,

D is the initial diameter of the work piece in mm,

N is the spindle speed in r.p.m.

1.2.2 Feed:

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$$F_m = f \times N \text{ (mm/min)}$$

Here,

F_m is the feed in mm per minute,

f - Feed in mm/rev and

N - Spindle speed in r.p.m.

1.2.3 Depth of Cut:

Depth of cut is practically self-explanatory. The thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface is expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work

$$D_{cut} = D - d/2$$

D_{cut} - Depth of cut in mm

D - Initial diameter of the work piece

d - Final diameter of the work piece

1.3 SINGLE POINT CUTTING TOOL

Single point cutting tools are commonly used in lathe, planers, Shapers machine for cutting operation. These tools are classified as left-handed and right-handed. A tool is said to be right-handed if their cutting edge is on the right side when the tool is viewed from the point end.

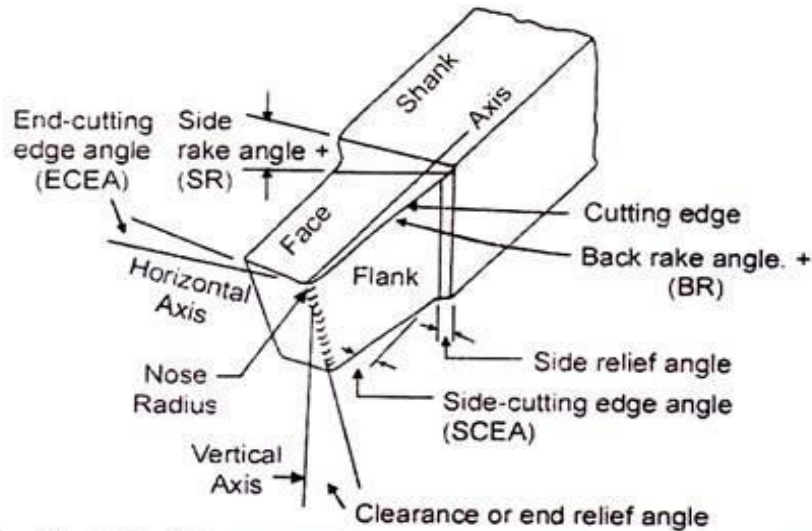


Figure 1. 1: Tool geometry of single point cutting tool

1.3.1 Terminology or Nomenclature of Single Point Cutting tool.

This specification is according to the American Standards Association (ASN) Systems.

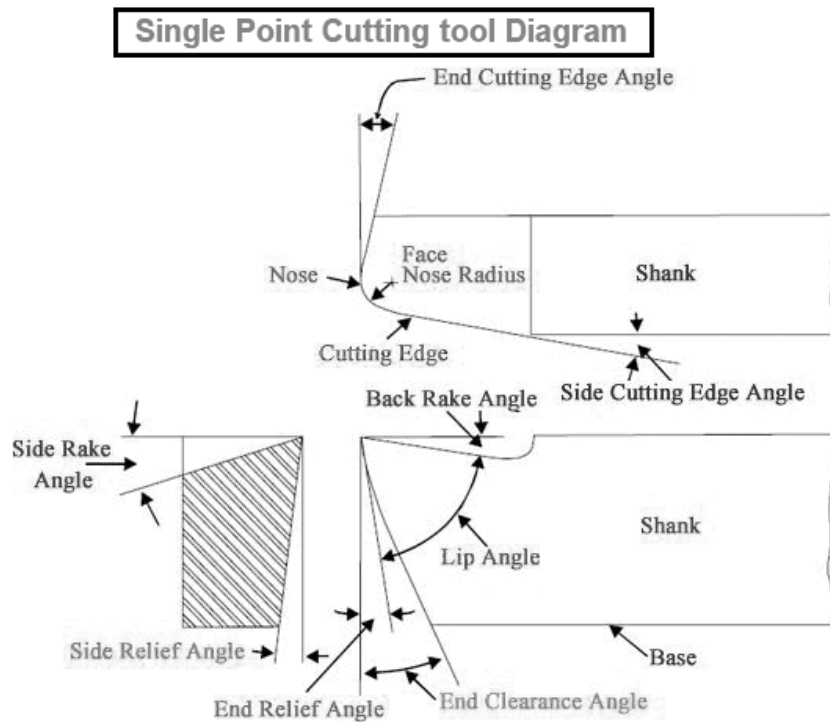


Figure 1. 2: Single-Point Cutting Tool Diagram

1. **Shank:**

The main body of the tool is known as the shank. It is the backward part of the tool which is held by tool post.

2. **Face:**

The top surface tool on which chips passes after cutting is known as a face. It is the horizontal surface adjacent of cutting edges.

3. **Flank:**

Sometime flank is also known as cutting face. It is the vertical surface adjacent to the cutting edge. According to cutting edge, there are two flank side flank and end flank.

4. **Nose or Cutting Point:**

The point where both cutting edge meets known as cutting point or nose. It is in front of the tool.

5. **Base:**

The bottom surface of the tool is known as the base. It is just the opposite surface of the face.

6. **Heel:**

It is an intersecting line of face and base.

7. **End Cutting Edge Angle:**

- The angle between the end cutting edge or flank to the plane perpendicular to the side of the shank is known as the end cutting angle.
- This angle usually varies from 5 to 15 degree

8. **Side Cutting Edge Angle:**

The angle between the side cutting edge or flank to the plane parallel to the side of the shank known as side cutting edge angle.

9. **Back Rake Angle:**

- The angle form to smooth flowing of chips from the face, known as rack angle. It allows to smooth flow of chips.
- The back rack angle is the angle between the face and the plane perpendicular to the end cutting edge.
- Softer the material, greater should be the positive rake angle.
- The back rake angle may be positive negative or neutral.

10. Side Rack Angle:

- The angle between the face and plane perpendicular to the side cutting edge is known as the side rack angle. It allows chips to flow smoothly when material cut by side cutting edge.
- The amount by which a chip is bent depends upon this angle. When the side rack angle increases, the magnitude of chip bending decreases. Smoother surface furnish is produced by a larger side rake angle.

11. End Relief Angle:

- It is also known as a clearance angle. It is the angle that avoids tool wear. It avoids the rubbing of flank with a workpiece.
- End cutting angle made by end flank to the plane perpendicular to the base.
- This angle may vary from 6 to 10 degrees.

12. Side Relief Angle:

- It is the angle made by the side flank to the plane perpendicular to the base. It avoids rubbing of side flank with a workpiece.
- This angle allows the tool to feed sideways into the job in order to cut the work material without rubbing.
- When the side relief angle is very small, the tool will rub against the job and therefore it will get overheated and become blunt and the surface finish obtained will be poor.

13. Nose Radius:

The intersecting area of both cutting edges is known as the nose of the tool.

1.3.2. Factors influencing rake angle of the single point cutting tool:

1. **Type of material being cut:** a harder material like cast iron may be machined with a smaller rake angle than that required by a soft metal like mild steel or aluminium.
2. **Type of tool material being used:** tool material like cemented carbide permits turning at a very high speed. It has been observed that in machining at a very high cutting speed rake angle has a little influence of cutting pressure.
3. **Depth of cut:** in rough turning, a high depth of cut is given to withstand severe cutting pressure. So, the rake angle should be decreased to increase the lip angle that provides strength to the cutting edge.
4. **The rigidity of the tool holder and condition of the machine:** an improperly supported tool on an old and worn-out machine can't take up severe cutting

pressure. so, machining under such conditions the tool used should have a larger rake angle than that at the normal condition to reduce the cutting pressure.

1.3.3. Tool Signature

The tool signature or tool designation is used to denote a standardized system of specifying the principal tool angles of a single-point cutting tool. Some common systems used for tool designation or tool nomenclature are the following-

1. **American or (ASA) System.**

It defines the principle angles like side rake, back rack, nose, etc. without any reference to their location concerning cutting edge. As such, this system of nomenclature does not give any indication of the tool behaviour with regard to the flow of chip during the cutting operation the three reference planes adopted for designating different tool angles are similar to those used in conventional machine drawing i.e., x-x, y-y, and z-z the last one containing the base of the tool and the two plane being normal to this plane as well as mutually perpendicular. Thus, this system is a coordinate system of tool nomenclature.

2. **British system:**

This system, according to B-S1886-1952, defines the maximum rake. The various tool parameters in this system are indicated if the order of Back rake, Side rake, End relief angle, Side relief angle, End cutting angle, Side cutting edge angle, and Nose radius.

3. **Continental systems:**

This category of tool nomenclature systems includes the German or DIN System (DIN-6581), Russian Systems (OCT-BKC 6897 and 6898), and Czechoslovakian System (CSN-1226). The various tool parameters in these systems are specified with reference to the tool reference to the tool reference planes.

4. **International system:**

It is an internationally adopted system, developed recently. It incorporates the salient features of tool nomenclature of different systems in it.

1.3.4. Single Point Cutting Tool Examples:

Single Point Cutting tool consists of only one main cutting edge that can perform material removal action at a time in a single pass.

1. Turning tool
2. Shaping tool
3. Planing tool
4. Slotting tool
5. Boring tool

6. Fly Cutter

1.3.5. Material Used for Single Point Cutting tools:

Tool bits generally made of seven materials

- High-speed steel
- Cast alloys (such as stellite)
- Carbides
- Ceramics
- Cermets
- Cubic Boron Nitride
- Polycrystalline Diamond

Advantages of Single Point Cutting Tool:

- Single Point Cutting tool is simple in construction hence easy to Design and Manufacture.
- As compare to multipoint cutting tool single point cutter are cheaper.’
- Resharpener of cutter is easy

Disadvantages of Single-point Cutting Tools:

- These tools have low material removal rates (MRR) hence productivity is low.
- The tool wear rate is high.
- Tool life is short.
- High Cutting temperature

1.4. LATHE MACHINE AND TYPES:

A lathe machine is a machine that holds the workpiece on a chuck and tool on a tool post, the lathe machine rotates the workpiece about an axis to perform different operations such as turning, facing, chamfering, thread cutting, knurling, drilling, and more with tools that are applied to the workpiece to design an object with symmetry about that axis.

The main function of a lathe is to remove the metal from a workpiece to give a required size and shape. In a lathe machine, the tool is held and a workpiece is rotating about an axis rotation to perform various operations with different tools. **The lathe** machine is primarily used to produce cylindrical surfaces and plane surfaces at a right angle to the axis

of rotation. It can also produce tapers and bellows etc. Most suitable lathes can also be still used to produce most solids of revolutions, plane surfaces & screw threads, etc.

1.4.1. Parts of Lathe Machine

The following are the main parts of lathe machine:

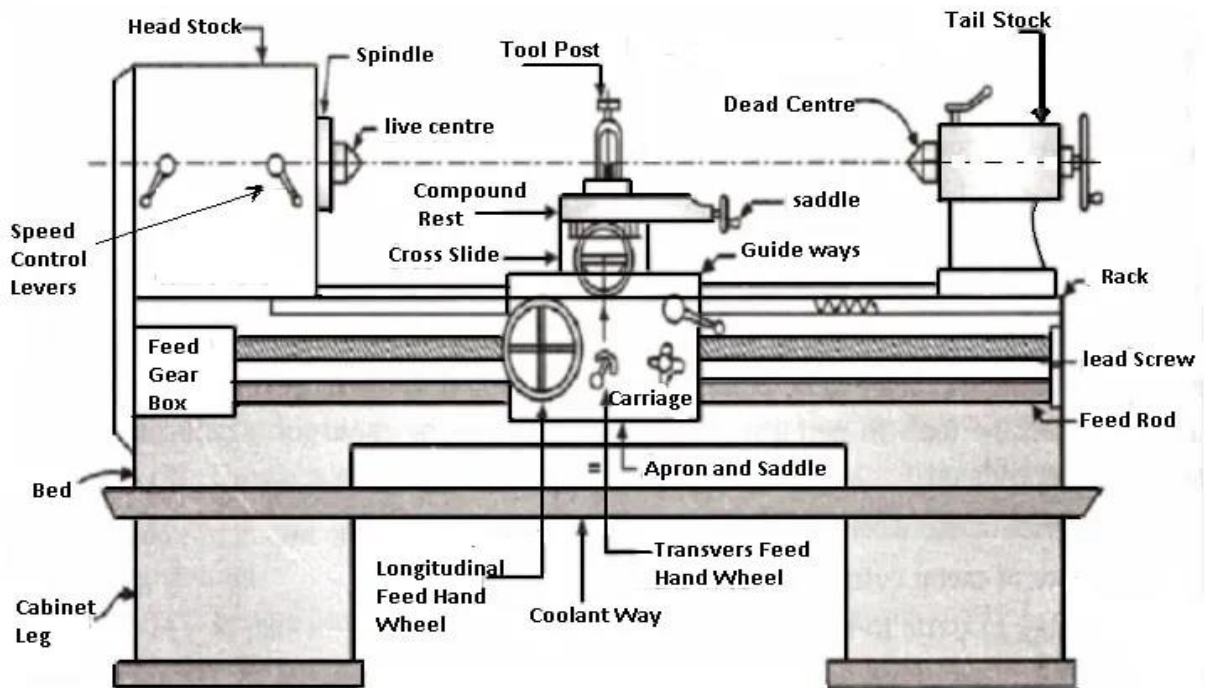


Figure 1. 3: Lathe Machine and Its Parts

1. Bed
2. headstock
3. Carriage
4. Feed mechanism
5. Tailstock
6. Screw or thread cutting mechanism
7. Feed rod
8. Lead screw

1. Bed

The lathe bed is the base of the machine, which is a solid structure. It should be provided strictly under heavy pressure. On top of the bed, has the V-type of guideways include the angle of 90° .

There are two guideways provided, inner ways and outer ways, which are accurately machined to make them parallel to the axis. The lathe should take up the various vibrations, which are causing due to different types of force. The guideways provide sliding surfaces to the carriage and the tailstock.

The lathe bed must-resist stresses due to the results of two important forces,

- The downward cutting force on the tool
- The force tending to move the tool away from the workpiece in a horizontal direction.

2. Headstock

- H1: Geared headstock housing,
- H2: Intermediate gears lever,
- H3: High Low gear lever,
- H4: Camlock spindle,
- H5: Tumbler gears – forward/reverse and engage/disengage,
- H6: Quick change gearbox with 4 selectors (3 levers),
- H7: Lead screw
- H8: Feed screw,
- H9: Forward reverse switch,
- H10: Change gear cover



Figure 1. 4: Head Stock of a Lathe Machine

It is located on the left-hand side of the lathe bed. It has a hollow spindle and the different types of mechanism for driving and changing the speed of the spindle.

In this case, the speed increases when the belt is shifted from larger to smaller diameter pulleys. The spindle is made up of nickel, chrome steel and carbon steel. The front end of the spindle hole is taper for holding the centres perfectly.

The speed changing is based on the following conditions,

1. The type of material to be cut

- Hard and tough materials like cast iron – slow speed
- Soft materials like aluminium, brass – high speed.

2. Type of cutting tool material

- For high – speed hard tools made of tungsten carbide is used.
- For slow – speed medium hardness tool is used.

3. The type of finish-finishing cut-small depth-high speed

- Rough cut – high depth – low speed.

4. The diameter of the workpiece

- For large diameter workpiece – low speed
- For smaller diameter workpiece – high speed

5. Type of operation

- For turning, boring, drilling – high speed
- For thread cutting, tapping, reaming – low speed.

3. Tailstock

The tailstock is located on the right-hand side of the lathe bed. The tailstock supports the other end of the workpiece when it is machining between two centres.

- T1: A feed screw
- T2: Reduction gearbox (optional)
- T3: Body
- T4: Adjustable base
- T5: Spindle
- T6: Locking Lever



Figure 1. 5: Tail Stock of a Lathe Machine

It holds the tool rigidly and perfectly for performing operations such as drilling, reaming, tapping, and boring. It can move along the guideways and can clamp in any position on the bed.

The tailstock is consisting of the dead centre, spindle, adjusting screw, hand wheel, etc. The spindle can move forward and backward of the body called barrel by means of a handwheel. The keyway is provided on the inside surface of the barrel to hold the dead centre.

4. Carriage

The carriage is one of the most important parts of the lathe tool and it will serve as a supporting, moving, and controlling part of the cutting tool.

a) Saddle

It is 'H' shaped. The saddle fits over the bed and slides along the guideways by carrying the cross slide and tool post. It can lock in any position in its movement.

b) Cross Slide

It is an attachment to the saddle and to the compound rest. The cross-slide move by the turning handwheel. Transverse movement is obtained when the nut mounted on the feed screw is engaged with the binder screw of the cross slide.

When a taper turning attachment is used the binder screw is open to disconnect the cross slide from the cross-feed screw and the cross slide is attached to the guide block. Cross slide can move automatically when the pinion is keyed to the cross-feed screw is in mesh with the apron gearing.

c) Compound rest

It is a circular base, graduated in degrees and it is used to obtain angular cuts and tapers of the variable cross-section. It consists of a compound slide handwheel, compound slide feed screw, compound slide nut. The compound slide handwheel is mainly used in taper turning operations to give the feed.

d) Tool post

The tool post is placed above the compound rest and it holds the tool firmly. There are different types of tool post,

- Single screw tool post
- Four-way tool post
- Eight-way tool post

e) Feed mechanism

The amount of the tools relative to the workpiece is called 'Feed'.

- A lathe tool has 3 types of feed

- **Longitudinal feed:** Here the tool moves parallel to the lathe axis. It is affected by means of the carriage movement.
- **Cross-feed:** Here the tool moves at right angles to the lathe axis.
- **Angular feed:** By adjusting the compound slide and swivelling it to the required angle to the lathe axis.

Cross and longitudinal feeds are both hand and power operated, but angular is only hand operated.

f) Screw or Thread Cutting Mechanism

The lathe is important to the machine tool, which is used to cut the required type of threads on a given work. The rotation of the screw is used to move the tool along the workpiece to produce the screw threads. The half-nut mechanism is used in the lathe.

g) Feed Rod

It is a long shaft having a keyway extends from the feed box across and in front of the bed. The power is transmitted from the lathe spindle to the apron gears through the feed rod.

The feed rod is mainly using to move the carriage or cross slide for the operations such as turning, boring, facing and all other considering the thread cutting operation.

h) Leadscrew

It is a long-threaded shaft used for only thread cutting operation. The lead screw is in an arranged position in all operations from the gearbox. It may also be used to give the motion for turning, boring, etc., in the lathes which are equipped with a feed rod.

1.4.2. Types of Lathe Machines

Following are the seven different types of lathe machine:

1. Speed Lathe Machine
2. Engine Lathe Machine
3. Bench Lathe Machine
4. Toolroom Lathe Machine
5. Capstan and Turret Lathe Machine
6. Special purpose lathe machines
7. Automatic Lathe Machine
8. CNC lathe machine

1.5 WORKPIECE MATERIALS AND THEIR SPECIFIC APPLICATIONS.

Stainless steels get their names from the American Iron & Steel Institute (AISI) and the Society of Automotive Engineers (SAE), who have separately created their own naming systems for steel alloys based on alloying elements, uses, and other factors. Steel names can get confusing, as the same alloy can have different identifiers depending on which system is used; however, understand that the chemical composition of most alloy blends remains the same across classification systems. In the case of stainless steels, they are often composed of 10 to 30% chromium and are made to withstand varying degrees of corrosion exposure. To learn more about the differences among stainless steels, feel free to read our article on the type of stainless steel.

Type 304 steel is part of the 3xx stainless steels or those alloys which are blended with chromium and nickel. Below is a chemical breakdown of 304 steel:

- $\leq 0.08\%$ carbon
- 18-20% chromium
- 66.345-74% iron
- $\leq 2\%$ manganese
- 8-10.5% nickel
- $\leq 0.045\%$ phosphorus
- $\leq 0.03\%$ sulfur
- $\leq 1\%$ silicon

1.5.1 Corrosion resistance & temperature effects

Type 304 steel, being the most popular stainless steel, is naturally chosen for its corrosion resistance. It can resist rusting in many different environments, only being majorly attacked by chlorides. It also experiences increased pitting in warm temperatures (above 60 degrees Celsius), though the higher carbon grades (304H) mitigate this effect considerably. This means that 304 steel mainly rusts not in high temperatures, but in aqueous solutions where continuous contact with corrosive materials can wear down the alloy.

1.5.2 Applications of 304 Steel

304 steel is often referred to as “food-grade” stainless steel, as it is unreactive with most organic acids and is used in the food processing industry. Its excellent weldability, machinability, and workability suits these stainless steels to applications that require a level of corrosion resistance as well as complexity. As a result, 304 has found many uses, such as:

- Kitchen equipment (sinks, cutlery, splashbacks)

- Tubing of various types
- Food equipment (brewers, pasteurizers, mixers, etc.)
- Pharmaceutical processing equipment
- Hypodermic needles
- Pots and pans
- Dyeing equipment

as well as other uses.

AISI 304 has good machinability, however, its low thermal conductivity means coolants and lubricants should be used liberally, especially on the cutting edges.

1.6 CUTTING TOOLS USED IN TURNING

The specimen used in this experimentation have a high hardness so for better machining purpose Tungsten Carbide cutting tool is chosen in this project.

Tungsten carbide plays an outstanding role in the machining process because it offers a considerably higher wear resistance than high-speed steel (HSS), can withstand higher working temperatures and can be very well optimized to meet the requirements of various processes. At the same time, it is significantly less expensive than tools with polycrystalline diamond (PCD) coating, for example.

At the cutting edge, carbide tools can withstand temperatures of up to 1,100°C with minimal creep, allowing higher cutting speeds and feed rates.

1.7 TEMPERATURE GUN MEASUREMENT

Temperature guns have electronic sensors that enable them to collect the amount of heat energy from a given object whose temperature would otherwise be difficult to measure. These guns often use infrared beams, and you only have to aim at the object whose



Figure 1. 7: Temperature Gun

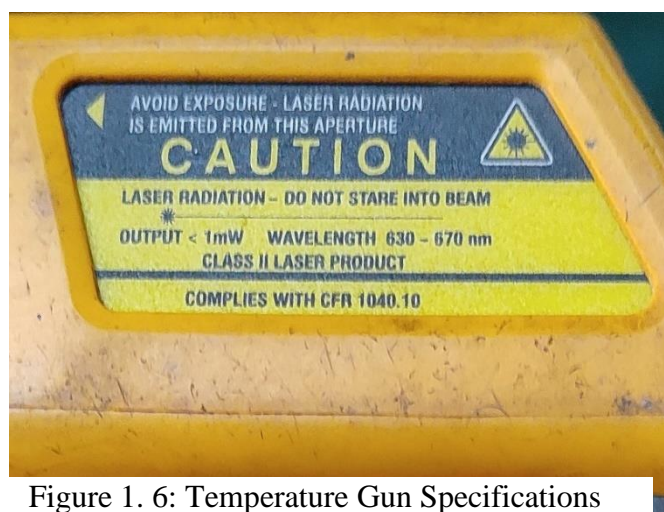


Figure 1. 6: Temperature Gun Specifications

temperature you are interested in measuring without touching it. The sensors have the capability to collect the accurate temperature provided the gadget is functional. There are, however, some basics that you must know to use these temperature guns correctly. First, the temperature gun uses beams to collect information on the heat energy coming from a given object. Thus, the gun does not state whether the heat comes from the intended object or the surroundings. This means that to collect the correct temperature measurement, you will have to ensure that you point the gun directly at the object whose temperature you intend to measure. You need to be as close as possible to avoid reading other heat waves that may interfere with your reading's accuracy. The gun will only read the heat energy on the area where it is pointing, and for accuracy, you must aim directly at the object whose temperature you intend to measure.

1.8 INTRODUCTION TO MINITAB

Minitab is a statistics package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of OMNITAB, a statistical analysis program by NIST. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania, with subsidiaries in Coventry, England (Minitab Ltd.), Paris, France (Minitab SARL), and Sydney, Australia (Minitab Pty.).

Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI, and other statistics-based process improvement methods. Minitab 16, the latest version of the software, is available in 7 languages: English, French, German, Japanese, Korean, Simplified Chinese, & Spanish. Minitab is statistical analysis software. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals. Minitab Inc. produces two other products that complement Minitab 16: Quality Trainer, an eLearning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 16 to simultaneously develop the user's statistical knowledge and ability to use the Minitab software and Quality Companion 3, an integrated tool for managing Six Sigma and Lean Manufacturing projects that allows Minitab data to be combined with management and governance tools and documents.

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of commands, graphs, and worksheets. Every time you save a Minitab project, you will be saving graphs, worksheets, and commands. However, each one of the elements can be saved

individually for use in other documents or Minitab projects. Likewise, you can print projects and their elements.

1.8.1 Minitab Project and Worksheets.

Minitab has two main types of files, projects, and worksheets. Worksheets are made up of data; think of a spread sheet containing data variables. Projects are made up of commands, graphs, and worksheets. Every time you save a Minitab project, you will be saving graphs, worksheets, and commands. However, each element can be saved individually for use in other documents or Minitab projects. Likewise, you can print projects and their elements.

The Menu bar: You can open menus and choose commands. Here you can find the built-in routines.

The Toolbar: Shortcuts to some Minitab commands.

1.8.2 Two windows in MINITAB

1. Session Window: The area that displays the statistical results of your data analysis and can also be used to enter commands.

2. Worksheet Window: A grid of rows and columns used to enter and manipulate the data. Note: This area looks like a spreadsheet but will not automatically update the columns when entries are changed.

Other windows include:

- Graph Window: When you generate graphs, each graph is opened in its own window.
- Report Window: Version 13 has a report manager that helps you organize your results in a report.
- Other Windows: History and Project Manager are other windows. See Minitab help for more information on these if needed

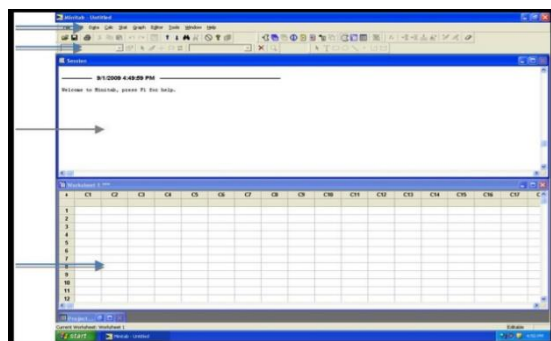


Figure 1. 8: Minitab Interface

1.9 INTRODUCTION TO TOPSIS

TOPSIS, known as **T**echnique for **O**rders of Preference by **S**imilarity to **I**deal **S**olution, is a multi-criteria decision analysis method. It compares a set of alternatives based on a pre-specified criterion. The method is used in the business across various industries, every time we need to make an analytical decision based on collected data.

Let's imagine the situation when we want to compare several companies and find out which one has the strongest financials. These companies are our alternatives set. To combine them together and decide which one is the strongest, we need to employ some reliable metrics. In such a case we can use some indicators derived from financial statements like for example **ROA** (return on assets), **ROE** (return on equity), **DR** (debt ratio), or **CG** (capital gearing). These indicators will form our criteria set.

The mysterious logic of **TOPSIS** is based on the concept that the chosen alternative should have the shortest geometric distance from the best solution and the longest geometric distance from the worst solution. Pretty simple huh?

Such methodology allows finding trade-offs between criteria when a poor performance in one can be cancelled by a good performance in another criterion. This provides a pretty comprehensive form of modelling because we are not excluding alternative solutions based on pre-defined thresholds.

1.9.1 TOPSIS algorithm

Generally, the whole **TOPSIS** process can be encapsulated in 7 steps:

1. Create a matrix consisting of **M** alternatives and **N** criteria. This matrix is usually called an "evaluation matrix".

$$(a_{ij})_{M \times N}$$

As an example: **M** will be the number of our companies, while **N**, the number of metrics (ROA, ROE, DR, CG).

2. Normalize evaluation matrix:

$$\alpha_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^M (a_{ij})^2}}$$

Each metric **j** for each company **i** is normalized to be in between 0 and 1. The higher its value the better the metric.

3. Calculate the weighted normalized decision matrix. It is important to note that each criterion should have its own weight so that all of them will sum up to 1. The weights can be derived randomly (not recommended) or based on expert knowledge (industry standard).

$$\chi_{ij} = \alpha_{ij} * \omega_j$$

$$\omega_j = \frac{w_j}{\sum_{j=1}^N w_j}$$

$$\sum_{j=1}^N \omega_j = 1$$

After we assign a weight to each financial metric, we need to normalize those so that these sum up to 1. Then we need to multiply each normalized metric from step 2 by corresponding normalized weight.

3. Determine the best and the worst alternative for each criterion:

$$\chi_j^b = \max_{i=1}^M \chi_{ij}$$

$$\chi_j^w = \min_{i=1}^M \chi_{ij}$$

We want to find the maximum and minimum value of each financial metric among all companies.

5. Calculate the Euclidean distance between the target alternative and the best/worst alternative:

$$d_i^b = \sqrt{\sum_{j=1}^N (\chi_{ij} - \chi_j^b)^2}$$

$$d_i^w = \sqrt{\sum_{j=1}^N (\chi_{ij} - \chi_j^w)^2}$$

This is a calculation of the geometric distance between the value of each financial metric for a given company i and the best/worst value of such a metric among all companies.

6. For each alternative calculate the similarity to the worst alternative. The results are our **TOPSIS** scores.

$$S_i = \frac{d_i^w}{d_i^w + d_i^b}$$

We compute a score for each company that is based on distances obtained in a step before.

7. Rank alternatives according to the **TOPSIS** score by descending order.

CHAPTER 2. LITERATURE STUDY

1. João Ribeiro has observed that the Taguchi method shows to be very robust method and allowed to improve the surface roughness. For a specific range of parameters, the experimental results from the Taguchi method and ANOVA analysis one could identify the test 7 with a cutting speed of 250 m/min, the feed rate of 0.075 mm/t and the depth of cut of 0.312 mm as the best cutting parameters, leading to average surface roughness of 1.662 μm . By comparing the results from confirmation test implemented for the optimal combination (A3B1C3) and the combination A2B2C2, was verified an improvement of 22% for the mean value of Ra. From the ANOVA analysis we could identify the most influent parameter to be radial depth of cut with a contribution of 64% for the surface average roughness.
2. Rahul Davis has observed that the parameter designs yielded the optimum condition of the controlled parameters, as well as a predictive equation was used. A confirmation tests was then performed which indicated that the selected parameters and predictive equation were accurate to within the limits of the measurement instrument. Therefore, the above results can be recommended to get the lowest surface roughness for further studies. The experimentation can also be done for other materials having more hardness to see the effect of parameters on Surface Roughness.
3. Dharindom Sonowal has observed that the effect of Spindle speed (A), Feed (B) and Depth of Cut (C) are found significant both on the mean and variation of the surface roughness of AISI1020 mild steel in turning operation. Among the three variable factors feed has the maximum effect both on mean (50.650%) and variation (62.727%) of the output variable. However mild two factor interactions are observed among the three factors (Spindle speed x feed, Spindle speed x depth of cut and feed x depth of cut) which have a significant effect on mean only. Within the range of experiment, the optimum factor combination for the minimum surface roughness is found to be 630 rpm Spindle speed, 0.05 mm/rev feed and 1.25 mm depth of cut with estimated surface roughness $2.358 \pm 0.970 \mu\text{m}$.
4. Huu-Phan Nguyen has studied that in this study, the quality criteria (MRR, SR, and HV) in fine PMEDM using Ti powder for die steels (SKD61, SKD11, and SKT4) have been optimized by the Taguchi–TOPSIS method. This has confirmed the beneficial effects of Ti powder mixed into dielectric fluid for efficient EDM processing. When titanium powder is mixed into the dielectric fluid, MRR is increased, SR is reduced, and HV is increased. When the TOPSIS method is combined with the Taguchi method, we obtain the following: a number of optimized process parameters, reduced cost and time of the experiment, and the multi-objective optimization problem is solved simply.

5. Yahya Isik has studied that based on the results of the experimental investigation the following conclusions can be drawn, the coolant helps breaking up chips and removing them from the cutting area more efficiently, which means the cutting tool spent less time for breaking metal chips. The cutting fluid has significantly reduced the amount of heat and friction at the point where a tool cuts into a metal work piece. For most tests, cutting speed did not show a significant effect on surface roughness for both dry and wet machining conditions. The effect of the cutting speed is negligible. The results of the present work indicated that cutting fluid did not show a significant improvement on surface roughness particularly when cutting tests with 0.8 mm nose radius were considered.

6. Tanveer Hossain Bhuiyan and Imtiaz Ahmed have been formulating a suitable cutting force model with respect to several criteria and constraints has been one of the most valued research topics for the researchers in the machining field for quite a long time. Again, with recent advances in the field of expert systems it has become easier to optimize this model with the appropriate expert system. In this research, a model of the main cutting force (P_z) has been formulated during turning of AISI-1040 steel in dry machining condition, where the cutting force is considered as a function of the cutting speed (V_c) and feed rate (S_0). Using this model, the value of the cutting force can be predicted for a given set of cutting speed and feed rates.

7. K. Venkataraman has studied that in this work carbon steel is taken as a work material and tungsten carbide as tool material. By varying the different parameters like depth of cut, speed and feed at different conditions the tool life, surface finish, machining time and other parameters were calculated. The optimized results showed that the combined effective surface finish (0.0040 Ra), tool life, material removal rate and machining time. The optimized result also indicates the optimized cutting force in Ansys

8. Neeraj Saraswat had adopted the Taguchi method for the design of experiments and results have been by minimizing S/N ratio. Optimization of the surface roughness was done using Taguchi method and Predictive equation was obtained. A confirmation test was then performed which depicted that the selected parameters and predictive equation were accurate to within the limits of the measurement instrument.

9. Omar Zurita has observed that surface roughness increases when depth of cut (d) and feed rate (f) increase, while decreases with higher cutting speeds (V_c). Furthermore, cutting speed contributes 69.35%, feed rate 30.13% and depth of cut 0.52 % to surface roughness.

Finally, the developed mathematical expression can be used to predict optimum cutting parameters for minimum surface roughness.

10. Muhammad Yusuf has studied that the minimum values of surface roughness are the good quality, it obtained during wet and dry turning process with the parameters model ($v = 88$ mm/min, $f = 0.05$ mm/rev, $a_p = 0.25$ mm) and ($v = 129$ mm/min, $f = 0.05$ mm/rev, $a_p = 0.5$ mm). Muhammad Yusuf² and lowest (9.5 %) on the test no. 7. From the ANOVA, it was found that feed parameter is the most significant cutting parameter, which influences the surface roughness. Most significant interactions were found between cutting speed and feed parameters for dry turning process.

11. Neeraj Saraswat adopted the Taguchi design approach for the design of experiments and results have been by minimizing S/N ratio. Optimization of the surface roughness was done using Taguchi method and Predictive equation was obtained. A confirmation test was then performed which depicted that the selected parameters and predictive equation were accurate to within the limits of the measurement instrument.

12. Vivek Patel has studied that wet machining provided better surface finish as compared to dry machining of Inconel 718. Surface finishes improved mainly due to reduction of temperature at the tool tip by the application of lubricant. A good surface finish can be achieved at low depth of cut for the wet machining. Significant reduction in tooltip temperature is observed in wet machining. Maximum tool tip temperature observed during dry machining and wet machining were 64.15°C and 38.46°C.

13. Matheus Emmanuel Pereira Fernandes has observed that the LN₂ delivery system and the method used to measure the LN₂ flow rate were effective in supplying liquid nitrogen to the cutting zone in a controlled way. - Cryogenic turning with LN₂ was able to increase the cutting tool life in comparison with dry and wet machining, mainly at higher LN₂ flow rates. - The use of emulsion did not increase the cutting tool life in comparison with the dry condition. - There was a tendency for dry machining to provide the lowest production cost. - The production cost for the cryogenic condition increased as the LN₂ flow rate increased. - Production costs applying the wet and LN₂ Needle conditions were statistically the same.

14. Zulfiqar Ahmad Khan, Matthew Grover, and Mian Hammad Nazir has studied that during rough cutting it was noted that a high surface roughness was present with dry conditions, but was still at an acceptable level for noninterfacing surfaces, which would

suggest that for pure material removal operations, dry cutting is the most cost effective despite the slight increase in tool wear. The choice of wet and dry finish cutting highly depends on the intended application and the required amount of material needed to be removed. A compromise would be needed between the options either to use coolant or a slightly higher surface roughness with added manufacturing time.

15. Zhipeng Jiang , Dong Gao , Yong Lu and Xianli Liu have studied that although the cutting depth is set to a certain value, the total depth to be cut is not necessarily an integral multiple of the cutting depth. When the cutting depth is different from the set cutting depth in the last cutting, the cutting power of the machine tool will change. Therefore, this study calculated the processing time with the same cutting depth as the set cutting depth, and the processing time with a different cutting depth as the set cutting depth, which were called t_{cut-1} and t_{cut-2} , respectively.

16. Pramod George, D. Philip Selvaraj have studied that the optimal cutting parameters for Ra of 410 and 420 MSS grades are spindle speed at 1500 rpm and feed at 30 mm/min. It is found that Ra is most affected by spindle speed and then feed for both the grades. The spindle speed and feed are contributing to Ra of MSS 410 by about 65.97% and 31.11% with an error of 2.92%. For MSS 420, the contribution of speed and feed for the Ra are about 61.63% and 35.63% with an error of 3.01%. The experimental and predicted Ra values are very close with an error of 2.15% and 3.25% for 410 and 420 MSS grades, respectively.

17. Napsiah Ismail have studied that regardless of the category of the quality characteristic, the-lower-the better for surface roughness the lowest feed rate ($F = 0.05 \text{ mm rev}^{-1}$), the highest cutting speed ($S = 1400 \text{ RPM}$) and highest depth of cut ($D = 1.5 \text{ mm}$) lead to optimal surface roughness value. Similarly, the-higher-the better-quality characteristic for workpiece surface Temperature (T) follow significantly the-lower-the-better quality characteristic for surface roughness.

18. Lili Zhao, Yilin Fang, Ping Lou, Junwei Yan, Angran Xiao have studied that the architecture of digital twin of a CNC machine tool for cutting parameter optimization is presented, which describes the operation process of the proposed method. The ontology on CNC machining process is established for realizing real-time semantic understanding between physical machine tool and virtual twin model. A dynamic optimization method of cutting parameters based on dynamic perception of physical machining conditions and synchronous simulation of virtual twin model is proposed.

CHAPTER 3. DESIGN OF EXPERIMENTS

3.1 DESIGN OF EXPERIMENTS (DOE) OVERVIEW

In industry, designed experiments can systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, and field performance. As the resources are limited, it is essential to get the most information from each experiment performed. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. A well-designed experiment identifies the essential effects. If there is an interaction between two input variables

They should be included in the design rather than a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable.

Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification.

3.1.1 Planning

Careful planning help in avoiding the problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of system may affect the ability to complete the experiment. The preparation required before beginning experimentation depends on the problem. Here are some steps need to go through:

- Define the problem. Developing a good problem statement helps in studying the right variables.
- Define the objective. A well-defined objective will ensure that the experiment answers the right questions and yields practical, usable information. At this step, define the goals of the experiment.
- Develop an experimental plan that will provide meaningful information. Review relevant background information, such as theoretical principles and knowledge gained through observation or previous experimentation.

Make sure the process and measurement systems are in control. Ideally, both the process and the measurements should be in statistical control as measured by a functioning statistical process control (SPC) system. Minitab provides numerous tools to evaluate process control and analyse your measurement system.

3.1.2 Screening

In many processes' development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying

the key variables that affect product quality. This reduction allows focusing process improvement efforts on the crucial variables. Screening suggests the "best" optimal settings for these factors.

The following methods are often used for screening:

- Two-level full and fractional factorial designs are used extensively in industry
- Plackett-Burman designs have low resolution, but they are helpful in some screening experimentation and robustness testing.
- General full factorial designs (designs with more than two levels) may also be helpful for small screening experiments.

3.1.3 Optimization

After identifying the vital variables by screening, there is a need to determine the "best" or optimal values for these experimental factors. Optimal factor values depend on the process objective.

The optimization methods available in Minitab include general full factorial designs (designs with more than two levels), response surface designs, mixture designs, and Taguchi designs.

- Factorial Designs Overview describes methods for designing and analyzing general full factorial designs.
- Response Surface Designs Overview describes methods for designing and analyzing central composite and Box-Behnken designs.
- Mixture Designs Overview describes designing and analyzing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a particular class of response surface designs where the proportions of the components (factors), rather than their magnitude, are essential.
- Response Optimization describes methods for optimizing multiple responses. Minitab provides numerical optimization, an interactive graph, and an overlaid contour plot to help to determine the "best" settings to simultaneously optimize multiple responses.
- Taguchi Designs Overview describes methods for analysing Taguchi designs. Taguchi designs may also be called orthogonal array designs, robust designs, or inner-outer array designs. These designs are used for creating products that are robust to conditions in their expected operating environment.

3.1.4 Verification

Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

3.2 Advantages & DISADVANTAGES of DOE

DOE became a more widely used modelling technique superseding its predecessor one-factor-at-time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling essential parameters to obtain the best responses. DOE also can provide us with the most optimal set of parametric values to find the best possible output characteristics. Besides that, the mathematical model generated can be used as a prediction model to predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE functions so that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Most usually, experiments will have an error occurring. Some of them might be predictable, while some errors are just out of control. DOE allows us to handle these errors while continuing with the analysis. DOE is excellent when it comes to predicting linear behaviour. However, when it comes to nonlinear behaviour, DOE does not always give the best results.

3.3 FACTORIAL DESIGNS

3.3(a) Factorial Designs Overview

Factorial designs allow for the simultaneous study of the effects that several factors may have on a process. When experimenting, varying the factors simultaneously rather than one at a time is efficient in terms of time and cost and allows for studying interactions between the factors. Interactions are the driving force in many processes. Without the use of factorial experiments, essential interactions may remain undetected.

3.3(b) Screening designs

In many processes development and manufacturing applications, the number of potential input variables (factors) is significant. Screening (process characterization) reduces the number of input variables by identifying the key input variables or process conditions that affect product quality. This reduction allows focusing process improvement efforts on the few crucial variables. Screening may also suggest the "best" or optimal settings for these factors. Optimization experiments can then be done to determine the best settings. In industry, two-level full and fractional factorial designs and Plackett-Burman designs are often used to "screen" for the significant factors that influence process output measures or product quality. General full factorial designs (designs with more than two levels) may be used with small screening experiments.

3.3.1 Full factorial designs

In a complete factorial experiment, responses are measured at all combinations of the experimental factor levels. The combinations of factor levels represent the conditions at

which responses will be measured. Each experimental condition is called a "run," and the response measurement an observation. The entire set of runs is the "design."

3.3.1(a) Two-level full factorial designs

In a two-level complete factorial design, each experimental factor has only two levels. The experimental runs include all combinations of these factor levels. Although two-level factorial designs cannot fully explore a broad region in the factor space, they provide helpful information for relatively few runs per factor. Because two-level factorials can indicate significant trends, which are used to provide direction for further experimentation.

3.3.1(b) General full factorial designs

In a general complete factorial design, the experimental factors can have any number of levels. For example, Factor A may have two levels, Factor B may have three levels, and Factor C may have five levels. The experimental runs include all combinations of these factor levels. General full factorial designs may be used with small screening experiments or in optimization experiments.

3.3.2 Fractional factorial designs

In a full factorial experiment, responses are measured at all combinations of the factor levels, which may result in a prohibitive number of runs. For example, a two-level full factorial design with 6 factors requires 64 runs; a design with 9 factors requires 512 runs.

To minimize time and cost, can use designs that exclude some of the factor level combinations. Factorial designs in which one or more level combinations are excluded are called fractional factorial designs. Minitab generates two-level fractional factorial designs for up to 15 factors.

Fractional factorial designs are helpful in factor screening because they reduce the number of runs to a manageable size. The runs that are performed are a selected subset or fraction of the complete factorial design.

3.3.3 Plackett-Burman designs

Plackett-Burman designs are a class of resolution III, two-level fractional factorial designs often used to study the main effects. In a resolution III design, the main effects are aliased with two-way interactions. Minitab generates designs for up to 47 factors. Each design is based on the number of runs, from 12 to 48, and is always a multiple of 4. The number of factors must be less than the number of runs.

3.4 CHOOSING A FACTORIAL DESIGN

The design, or layout, provides the specifications for each experimental run. It includes the blocking scheme, randomization, replication, and factor level combinations. This information defines the experimental conditions for each test run. While experimenting, need to measure the response (observation) at the predetermined settings of the experimental conditions. Each experimental condition that is employed to obtain a response measurement

is a run. Minitab provides two-level full and fractional factorial designs, Plackett-Burman designs, and full factorials for more than two levels.

3.5 DESIGN OF EXPERIMENTS

3.5.1 Creating Taguchi Design

Use Minitab's general full factorial design option when any factor has more than two levels. Using this can create designs with up to 15 factors. Each factor must have at least two levels, but not more than 100 levels.

To create a general full factorial design

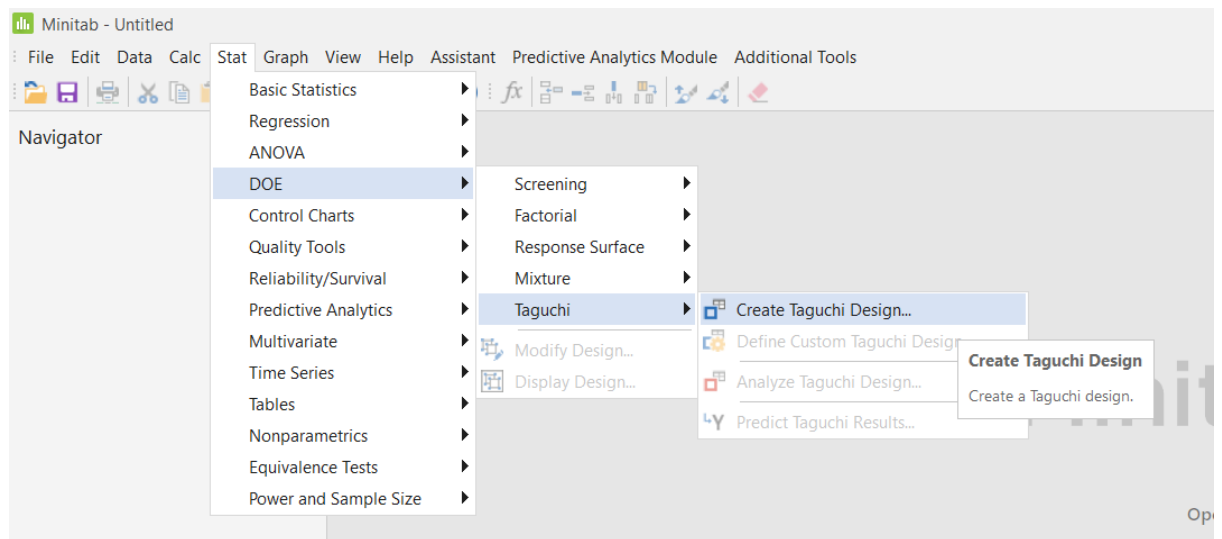


Figure 3. 1: Creating a Taguchi Design in Minitab

1. Choose Stat > DOE > Taguchi > Create Taguchi Design...

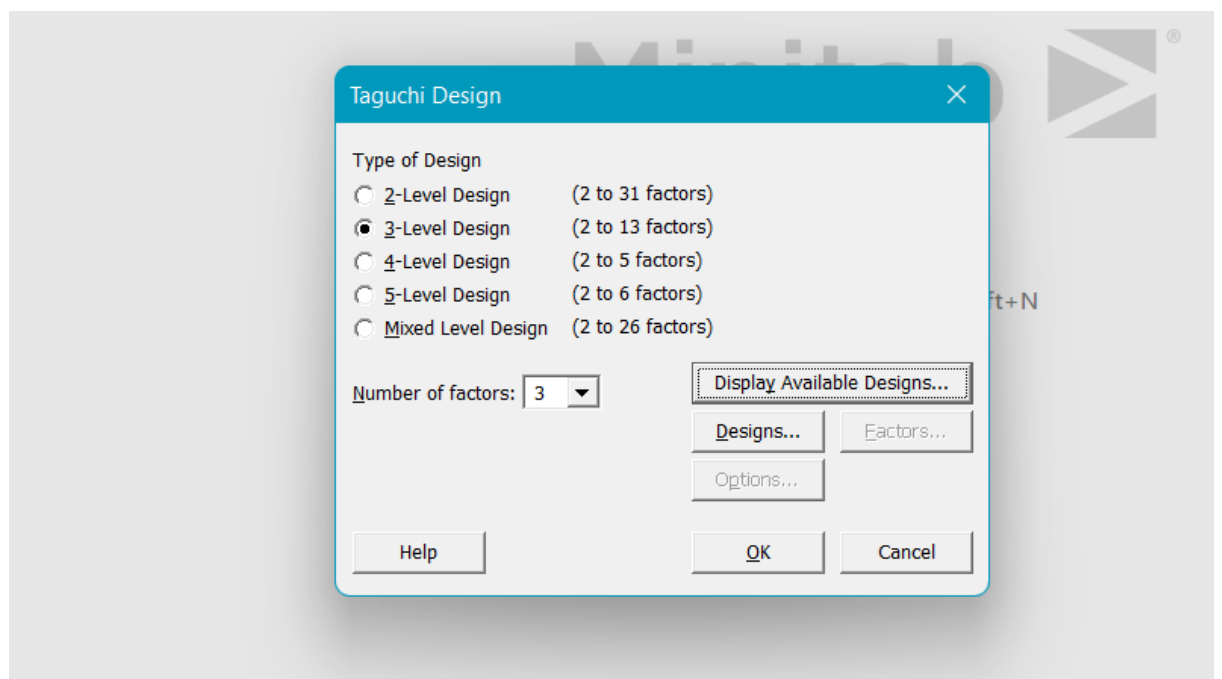


Figure 3. 2: Selection of Factors & Levels

2. From the Number of factors, choose a number from 3.
3. Select the 3-level Design (2 to 13 Factors).
4. Now Click on Display Available Options.
5. Selection of Available Taguchi Designs in Minitab

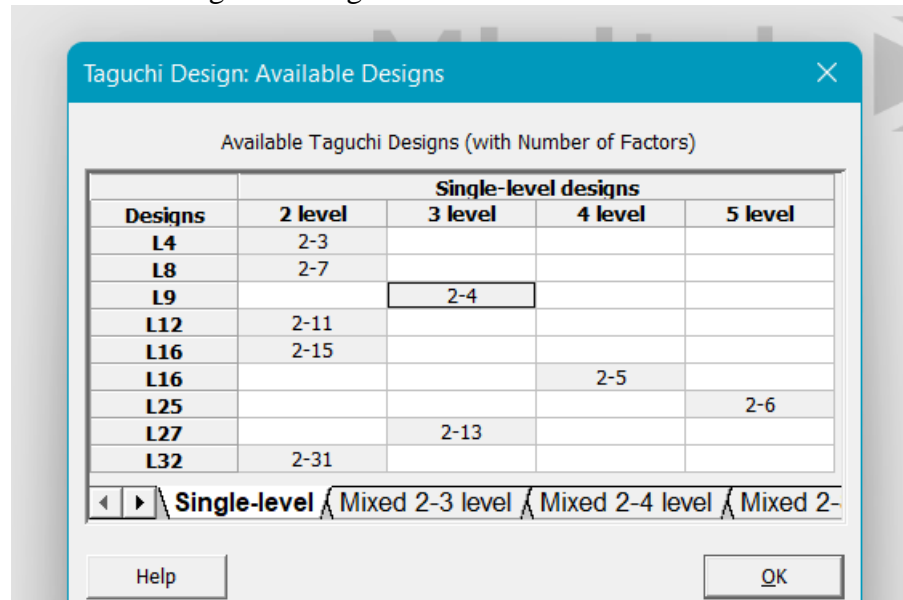


Figure 3. 3: Selection of Available Taguchi Designs in Minitab

6. A window will appear showing all the available Taguchi Designs (with number of Factors)
7. Now Select 2-4 Design with 3 level L9 Orthogonal Array and Click OK.

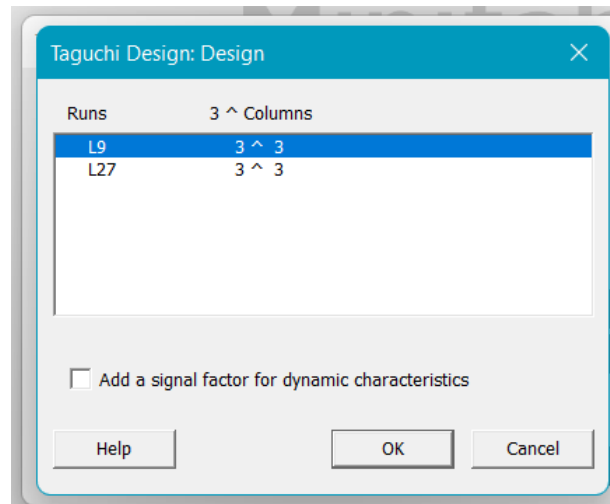


Figure 3. 4: Selection of Taguchi Design in Minitab

8. Now Click Designs and select L9 3^3 , and click on OK.

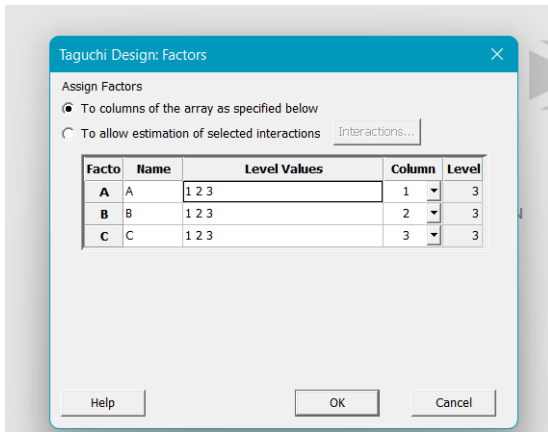


Figure 3. 5: Taguchi Design: Factors in Minitab

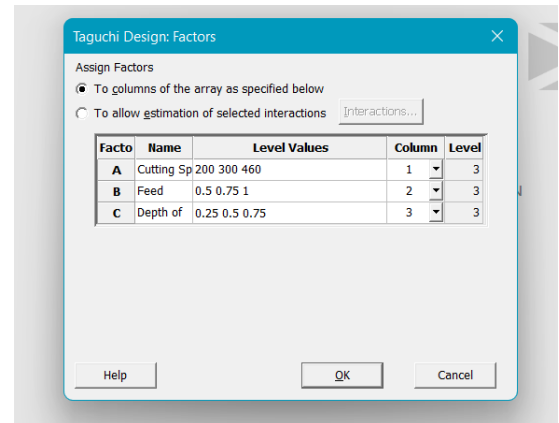


Figure 3. 5: Input of the Factors and their Values

9. Now Click Factors and a new window will appear showing the factors and their level values.

10. Double click on the Cells to edit and change the factors i.e., Factors A, B, C to Cutting Speed, Feed, Depth pf Cut.

11. Now double click on the Level Values cells to change the values and change cutting speed values to 200 300 400, Feed to 0.5 0.75 1, Depth of cut to 0.25 0.5 0.75. Now click OK.

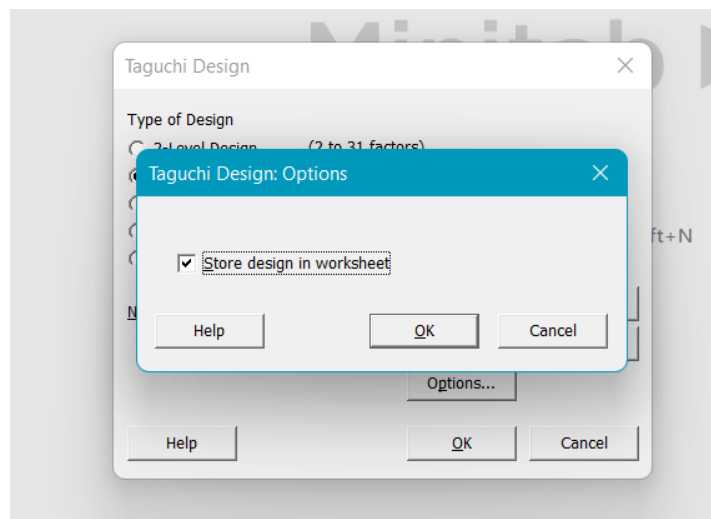


Figure 3. 6: Storing the Design in Worksheet

12. New window will and select the check box and click OK.

The screenshot displays the Minitab software interface for a Taguchi Design. The main window is titled 'Taguchi Design' and shows a 'Design Summary' section with the following details:

- Taguchi Array: L9(3^3)
- Factors: 3
- Runs: 9

Below the summary, it indicates 'Columns of L9(3^4) array: 1 2 3'. The main data table is a worksheet with columns labeled C1 through C18. The first three columns are 'Cutting Speed', 'Feed', and 'Depth of Cut', with their respective values for each of the 9 runs.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
1	200	0.50	0.25															
2	200	0.75	0.50															
3	200	1.00	0.75															
4	300	0.50	0.50															
5	300	0.75	0.75															
6	300	1.00	0.25															
7	460	0.50	0.75															
8	460	0.75	0.25															
9	460	1.00	0.50															
10																		
11																		
12																		

Figure 3. 7: Interface of the Minitab After Inputting the Values

CHAPTER 4. EXPERIMENTAL SETUP AND MACHINING

The project was done in 3 stages.

- Design of experiments was done using the full factorial method.
- Cycle time was calculated by machining the workpiece on lathe machine
- Analysis of results was done using MINITAB 17.1.30.

4.1 SELECTION OF PROCESS VARIABLES

- A total of three process variables and three levels are selected for the experimental procedure.
- The deciding process variables are
 - Speed
 - Feed
 - Depth of cut
- Speed of the spindle, i.e., the speed at which the spindle rotates the tool.
- Feed is the rate at which the material is removed from the work piece.
- Depth of cut is the depth up to which the tool is emerged in one cycle.

4.2 SELECTION OF LEVELS:

- Since it is a three-level design by observing the parameters taken in various projects, the levels of the factors are designed as follows

Table 4. 1 : Selection of process variables

FACTORS	LEVEL1	LEVEL2	LEVEL3
SPEED (RPM)	200	300	460
FEED (MM/REV)	0.5	0.75	1.0
D.O.C (MM)	0.25	0.5	0.75

4.3 DESIGN OF EXPERIMENTS:

Design of experiments was done using the Taguchi Design method.

Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the complete control of the experimenter or not.

4.4 SELECTION OF MATERIAL

Chemical composition % of the ladle analysis of grade SS 304 and Standards

Table 4. 2 : SS 304 Composition

Element	Content (%)
Iron, Fe	66.345-74
Chromium, Cr	18-20
Nickel, Ni	8-10.5
Manganese, Mn	≤ 2
Silicon, Si	≤ 1
Phosphorous, P	≤ 0.045
Carbon, C	≤ 0.08
Sulfur, S	≤ 0.03

The dimensions of the workpiece used are length 45mm*25 mm dia., 2 Pieces

4.5 EXPERIMENTATION

1. The work piece is clamped to the machine by using standard 3 jaw chuck.;



Figure 4. 1: Clamping of the work piece

2. The tool used for turning is Tungsten Carbide. Initially this tool is fixed in the tool turret using tool holding fixture.



Figure 4. 2: Tungsten Carbide Cutting Tool

3. The Workpiece is divided into 9 equal pieces according to the length of the rod using the outside calliper and the cutting tool.

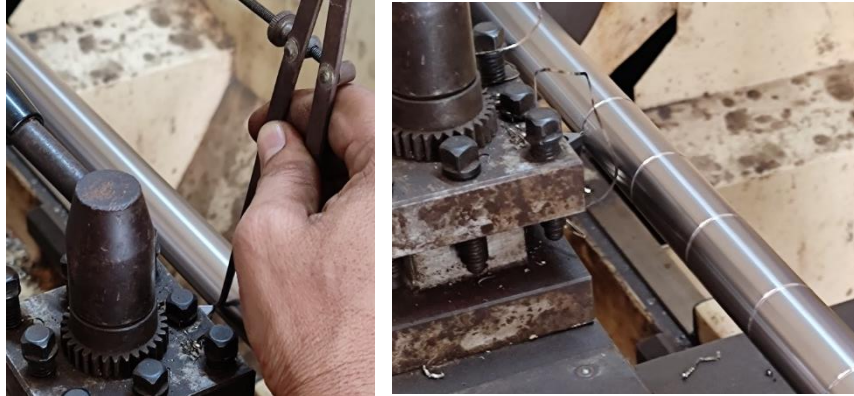


Figure 4. 3: Dividing the Workpiece into 9 equal parts

4. According to the Cutting Parameters 9 different machining operations are done.



Figure 4. 4: Machining operation

5. During the machining process the minimum and maximum temperatures are notes along with the time of the machining process.
6. After each machining process the weight of the rod is measured in order to calculate the material removal rate.
7. The chips are collected for calculating the chip thicknesses for.

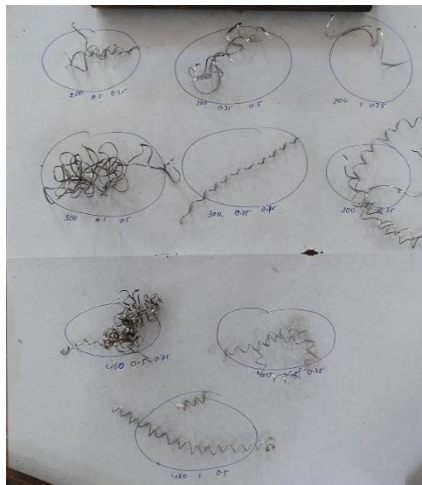


Figure 4. 5: Chips Obtained during Machining Process

8. The Chip thickness are measured using the vernier calipers.

9. The same process is repeated for the wet Turning with a cutting fluid.



Figure 4. 6: Cutting Fluid

4.6. CHIP THICKNESS RATIO

Chip thickness ratio (r_c) = a_1/a_2

a_1 = chip thickness before cutting

a_2 = chip thickness after cutting

4.7. SHEAR ANGLE

$$\tan \theta = \frac{(r_c \cos \alpha)}{(1 - r_c \sin \alpha)}$$

$$\theta = \tan^{-1} \left(\frac{(r_c \cos \alpha)}{(1 - r_c \sin \alpha)} \right)$$

θ = shear angle

r_c = chip thickness ratio

α = rake angle (i.e., 8°) [tool maker's microscope]

4.8. MATERIAL REMOVAL RATE

Material Removal Rate = $\frac{(\text{Material Removed})}{\text{Machining Time}} \times \text{Density of the workpiece}$

SAMPLE CALCULATION:

$$a_1 = 0.5$$

$$a_2 = 0.28 \text{ mm}$$

$$r_c = \frac{0.5}{0.28} = 1.786$$

$$\theta = \tan^{-1} \left(\frac{(r_c \cos \alpha)}{(1 - r_c \sin \alpha)} \right) = \tan^{-1} \left(\frac{1.786 \cos(8^\circ)}{(1 - 1.786 \sin(8^\circ))} \right) = \tan^{-1} \left(\frac{1.7686}{0.7514} \right) = 45.27^\circ$$

Machining Time = 35 sec

Initial Weight = 1.745 Kgs

Final weight = 1.736 Kgs

Material Removed = 1.745 - 1.736 = 0.009 Kgs = 9 g.

Density of SS 304 = 7.8×10^{-3} g/mm³.

$$\begin{aligned} \text{Material Removal Rate} &= \frac{(\text{Material Removed})}{\text{Machining Time}} \times \text{Density} \\ &= \frac{(9)}{35 \times 7.8 \times 10^{-3}} \\ &= 32.757 \text{ mm}^3/\text{sec} \end{aligned}$$

CHAPTER 5. RESULTS & DISCUSSIONS

5.1 TOPSIS ANALYSIS.

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method, which was originally developed by Ching-Lai Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS).

It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. An assumption of TOPSIS is that the criteria are monotonically increasing or decreasing. Normalization is usually required as the parameters or criteria are often of incongruous dimensions in multi-criteria problems. Compensatory methods such as TOPSIS allow trade-offs between criteria, where a poor result in one criterion can be negated by a good result in another criterion. This provides a more realistic form of modelling than non-compensatory methods, which include or exclude alternative solutions based on hard cut-offs. An example of application on nuclear power plants is provided in.

5.2 TOPSIS Algorithm

Generally, the whole **TOPSIS** process can be encapsulated in 7 steps:

1. Create a matrix consisting of **M** alternatives and **N** criteria. This matrix is usually called an “evaluation matrix”. $(a_{ij})_{M \times N}$

Table 5. 1: The values obtained from Dry Turning Operation

Tungsten Carbide Without Cutting Fluid								
Sl. No.	Cutting Speed	Feed	D. O. C	Temperature	Surface Roughness	Shear Angle	MRR	Chip Thickness
1	200	0.5	0.25	61	3.004	45.274	32.757	0.28
2	200	0.75	0.5	68	7.343	47.707	101.910	0.52
3	200	1	0.75	55	8.9	54.201	143.312	0.64
4	300	0.5	0.5	45	2.578	45.274	93.417	0.56
5	300	0.75	0.75	57	6.399	56.283	191.082	0.6
6	300	1	0.25	64	6.999	47.707	97.991	0.26
7	460	0.5	0.75	64	2.201	75.243	198.159	0.3
8	460	0.75	0.25	87	5.788	43.029	106.157	0.3
9	460	1	0.5	61	9.003	45.274	327.570	0.56

As an example: **M** will be the number of our companies, while **N**, the number of metrics (ROA, ROE, DR, CG).

2. Normalize evaluation matrix:

$$\alpha_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^M (a_{ij})^2}}$$

Table 5. 2: Normalized Matrix of Surface Roughness, Shear Angle, MRR, Temperature

Sl. No.	Cutting Speed	Feed	D. O. C	Surface Roughness	Shear Angle	MRR	Temperature
1	200	0.5	0.25	0.158	0.290	0.066	0.282
2	200	0.75	0.5	0.388	0.308	0.206	0.239
3	200	1	0.75	0.470	0.347	0.289	0.279
4	300	0.5	0.5	0.136	0.294	0.188	0.267
5	300	0.75	0.75	0.338	0.361	0.386	0.327
6	300	1	0.25	0.369	0.305	0.198	0.403
7	460	0.5	0.75	0.116	0.482	0.400	0.342
8	460	0.75	0.25	0.305	0.271	0.214	0.522
9	460	1	0.5	0.475	0.290	0.662	0.228

Each metric j for each company i is normalized to be in between 0 and 1. The higher its value the better the metric.

3. Calculate the weighted normalized decision matrix. It is important to note that each criterion should have its own weight so that all of them will sum up to 1. The weights can be derived randomly (not recommended) or based on expert knowledge (industry standard).

$$\chi_{ij} = \alpha_{ij} * \omega_j$$

Table 5. 3: Weighted Matrix

Sl. No.	Cutting Speed	Feed	D. O. C	Surface Roughness	Shear Angle	MRR	Temperature
1	200	0.5	0.25	0.039	0.072	0.016	0.070
2	200	0.75	0.5	0.097	0.076	0.051	0.060
3	200	1	0.75	0.117	0.086	0.072	0.070
4	300	0.5	0.5	0.034	0.072	0.046	0.067
5	300	0.75	0.75	0.084	0.090	0.096	0.082
6	300	1	0.25	0.092	0.076	0.049	0.101
7	460	0.5	0.75	0.029	0.120	0.100	0.085
8	460	0.75	0.25	0.076	0.06	0.053	0.130
9	460	1	0.5	0.119	0.072	0.165	0.057

After we assign a weight to each financial metric, we need to normalize those so that these sum up to 1. Then we need to multiply each normalized metric from step 2 by corresponding normalized weight.

4. Determine the best and the worst alternative for each criterion:

$$\chi_j^b = \max_{i=1}^M \chi_{ij}$$

$$\chi_j^w = \min_{i=1}^M \chi_{ij}$$

Table 5. 4: The Best and Worst Alternative for Each Criterion

V+	0.029076244	0.120622	0.165556916	0.057179728
V-	0.118933859	0.06898	0.016555666	0.130607247

We want to find the maximum and minimum value of each financial metric among all companies.

5. Calculate the Euclidean distance between the target alternative and the best/worst alternative:

$$d_i^b = \sqrt{\sum_{j=1}^N (\chi_{ij} - \chi_j^b)^2}$$

$$d_i^w = \sqrt{\sum_{j=1}^N (\chi_{ij} - \chi_j^w)^2}$$

Table 5. 5: The Euclidean Distance Between the Target and The Best/Worst Alternative

Sl. No.	Cutting Speed	Feed	D. O. C	Si+	Si-
1	200	0.5	0.25	0.157	0.099
2	200	0.75	0.5	0.139	0.082
3	200	1	0.75	0.133	0.084
4	300	0.5	0.5	0.128	0.110
5	300	0.75	0.75	0.096	0.102
6	300	1	0.25	0.146	0.052
7	460	0.5	0.75	0.071	0.140
8	460	0.75	0.25	0.151	0.056
9	460	1	0.5	0.101	0.166

This is a calculation of the geometric distance between the value of each financial metric for a given company and the best/worst value of such a metric among all companies.

6. For each alternative calculate the similarity to the worst alternative. The results are our **TOPSIS** scores.

$$S_i = \frac{d_i^w}{d_i^w + d_i^b}$$

Table 5. 6: The Performance Index of Dry Turning Process

Sl. No.	Cutting Speed	Feed	D. O. C	Pi
---------	---------------	------	---------	----

1	200	0.5	0.25	0.387084
2	200	0.75	0.5	0.369866
3	200	1	0.75	0.387369
4	300	0.5	0.5	0.46305
5	300	0.75	0.75	0.513237
6	300	1	0.25	0.263262
7	460	0.5	0.75	0.663382
8	460	0.75	0.25	0.271799
9	460	1	0.5	0.619859

- a) Rank alternatives according to the **TOPSIS** score by descending order.
- b) The same process is followed for the Machining process with wet turning and the performance index is obtained.

Table 5. 7: The Performance Index of Wet Turning Process

Sl. No.	Cutting Speed	Feed	D. O. C	Pi
1	200	0.5	0.25	0.456704356
2	200	0.75	0.5	0.3565392
3	200	1	0.75	0.419942952
4	300	0.5	0.5	0.52430278
5	300	0.75	0.75	0.661924571
6	300	1	0.25	0.24559839
7	460	0.5	0.75	0.803535097
8	460	0.75	0.25	0.444188103
9	460	1	0.5	0.647283033

5.3 ANALYZING TAGUCHI DESIGN IN MINITAB.

Step 1: Open the project file with the factors that are filled during the design of experiment process.

Step 2: Now fill the Performance indexes of both the Dry and Wet Turning Process that are obtained from the TOPSIS method.

Step 3: Now open the Stat ribbon > DOE > Taguchi > Analyze Taguchi Design...

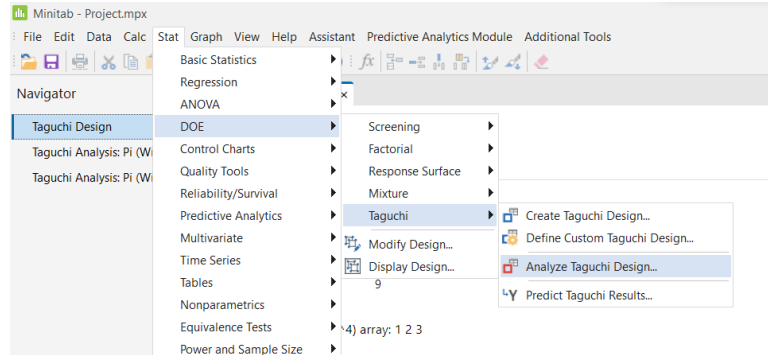


Figure 5. 1: Analysing process of Taguchi Design

Step 4: Now select one of the Performance Index and click on select.

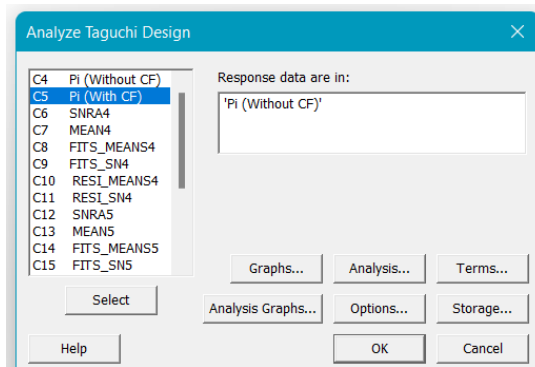


Figure 5. 2: Selection of The Performance Characteristic

Step 5: Now select on the Options and select the Signal to Noise Ratio to Larger is Better and click OK.

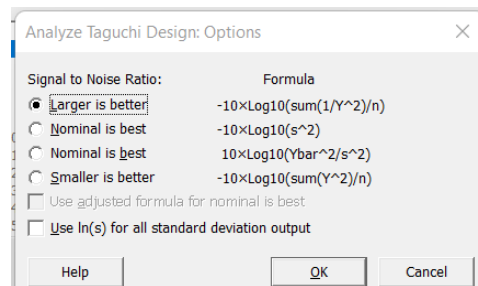


Figure 5. 1: Selecting the Suitable S/N Ratio

Step 6: Now select on the Storage and select the Signal to Noise Ratios, Means, Fits, Residuals and click on OK.

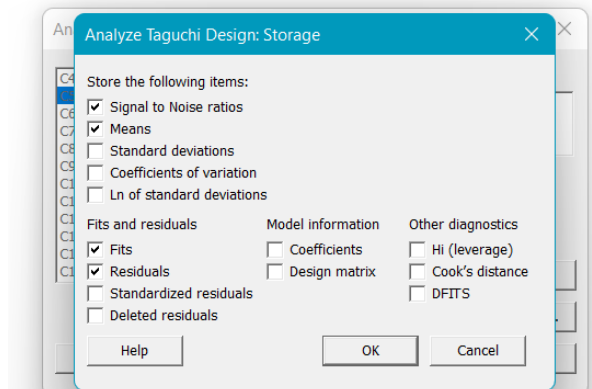


Figure 5. 4: Selection of the Parameters to be Stored in the worksheet

Step 7: Now select on the Analysis of Graphs and select the Histogram, Normal Plot, Residual vs Fits and click on OK.

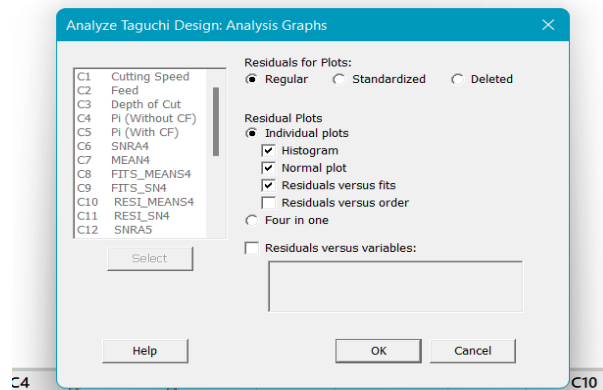


Figure 5. 5: Selection of the graphs to be obtained

TABLES AND GRAPHS

Table 5. 8: S/N Ratios for the Performance Index (Without Cutting Fluid)

Cutting Speed	Feed	Depth of Cut	Pi (Without CF)	SNR
200	0.50	0.25	0.387	-8.2439
200	0.75	0.50	0.369	-8.6391
200	1.00	0.75	0.387	-8.2375
300	0.50	0.50	0.463	-6.6874
300	0.75	0.75	0.513	-5.7936
300	1.00	0.25	0.263	-11.5922
460	0.50	0.75	0.663	-3.5647
460	0.75	0.25	0.271	-11.3151
460	1.00	0.5	0.619	-4.1541

The calculated Signal to Noise ratio of Performance Index (Without Cutting Fluid) are presented in Table 5.8. The Highest S/N ratio is at cutting speed 460rpm, feed 0.5, Depth of cut 0.75

Linear Model Analysis: SN ratios versus Cutting Speed, Feed, Depth of Cut

Estimated Model Coefficients for SN ratios

Table 5. 9: Estimated Model Coefficients for S/N Ratios of Dry Turning

Term	Coeff	SE Coeff	T	P
Constant	-7.5809	0.7941	-9.546	0.011
Cutting 200	-0.7926	1.1230	-0.706	0.553
Cutting 300	-0.4436	1.1230	-0.395	0.731
Feed 0.50	1.4155	1.1230	1.260	0.335
Feed 0.75	-1.0017	1.1230	-0.892	0.467
Depth of 0.25	-2.8029	1.1230	-2.496	0.130
Depth of 0.50	1.0873	1.1230	0.968	0.435

The Estimated model Coefficients for SN ratios are presented in the Table 5.9

Analysis of Variance for SN ratios

Table 5. 10: Analysis of Variance for S/N Ratios of Dry Turning

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Cutting Speed	2	7.060	7.060	3.530	0.62	0.617	11.05
Feed	2	9.535	9.535	4.767	0.84	0.543	14.92
Depth of Cut	2	35.944	35.944	17.972	3.17	0.024	56.25
Residual Error	2	11.351	11.351	5.675			17.76
Total	8	63.890					

Model Summary

Table 5. 11 Model Summary (Without Cutting Fluid)

S	R - Sq	R-Sq (adj)
0.1231	87.22%	48.87%

The ANOVA table for surface roughness is given in Table 5.10. It is observed that the R^2 value is 87.22 and hence confirms the consistency of the mathematical equation. From ANOVA table, it is noted that the highest contributing factor is the depth of cut with 56.25% of contribution.

Response Table for Signal to Noise Ratios

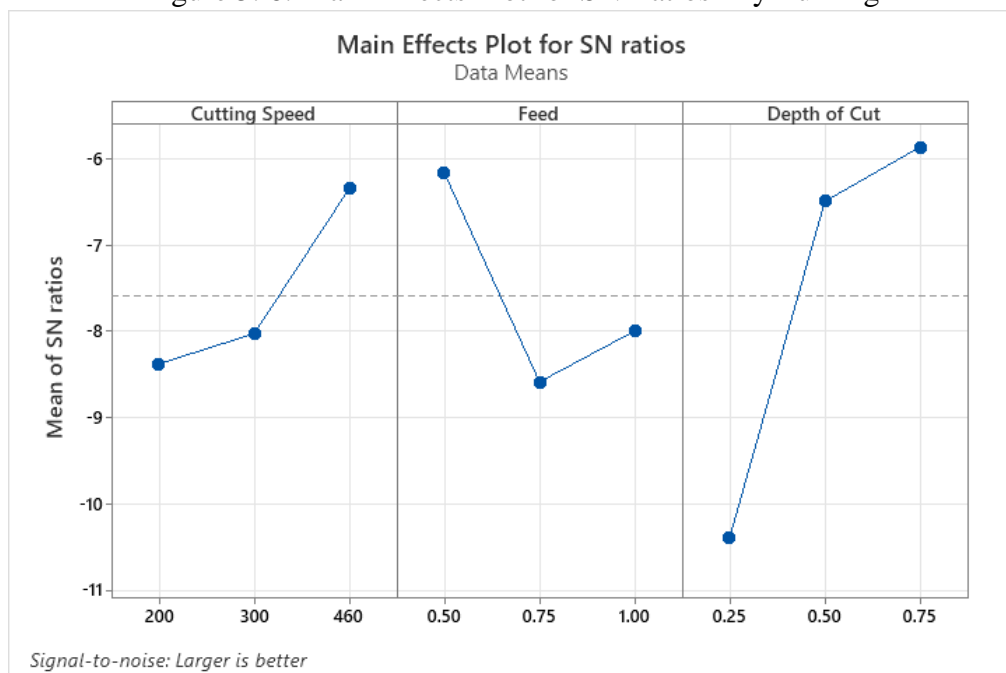
Larger is better

Table 5. 8: Response Table for Signal to Noise Ratios of Dry Turning

Level	Cutting Speed	Feed	Depth of Cut
1	-8.374	-6.165	-10.384
2	-8.024	-8.583	-6.494
3	-6.345	-7.995	-5.865
Delta	2.029	2.417	4.518
Rank	3	2	1

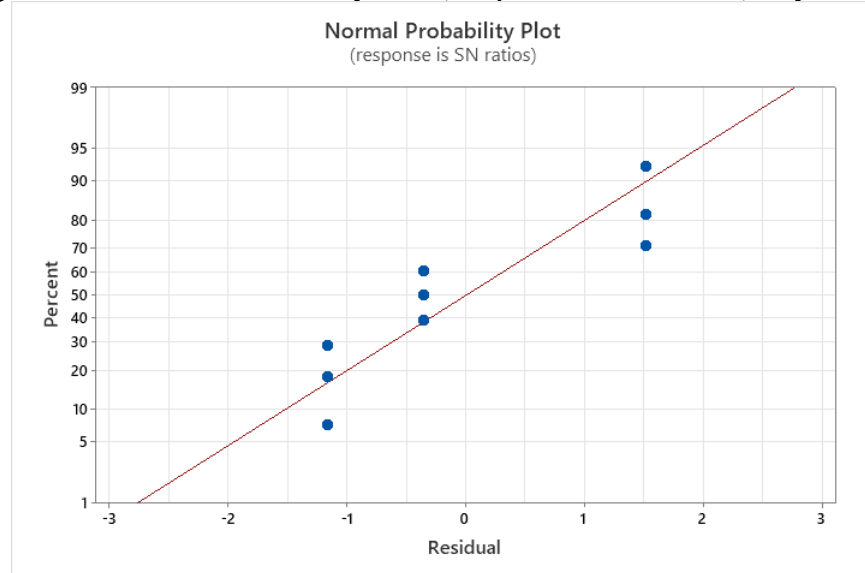
The response Table for signal to noise ratio for Surface roughness is shown in Table 5.12. It is observed that the depth of cut is the dominant parameter that affects surface roughness, material removal rate, temperature generated, shear angle followed by feed and depth of cut.

Figure 5. 6: Main Effects Plot for SN Ratios Dry Turning



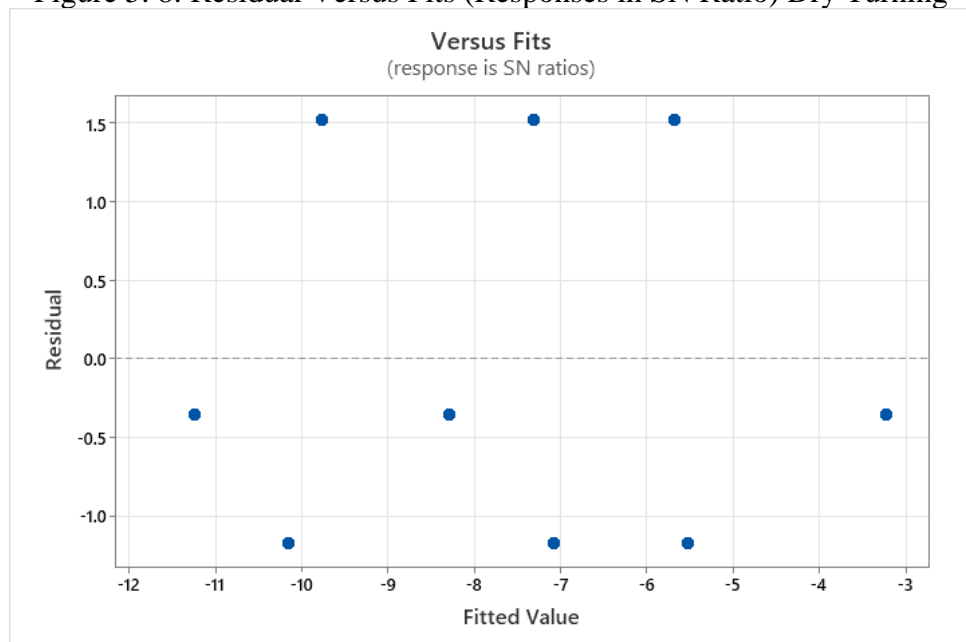
The main effects plot for S/N ratios roughness and Flank wear are shown in Figure 5.6. The optimized process parameter range for surface roughness and flank wear are; Surface Roughness, cutting speed = 460 rpm, feed = 0.5mm/rev, depth of cut = 0.75.

Figure 5. 7: Normal Probability Plot (Responses in SN Ratio) Dry Turning



The normal probability plot for surface roughness is shown in Figure 5.7. The middle line in the plot represents the expected probabilities among the distribution based on likelihood parameter estimates. The smooth curved line will be obtained if the distribution is good. Here it is observed that all points fall closer to the middle line and satisfy the adequacy of the surface roughness optimization.

Figure 5. 8: Residual Versus Fits (Responses in SN Ratio) Dry Turning



The Figure 5.8 plots the residuals versus the fitted values.

Figure 5. 9: Histogram (Responses in SN Ratio) Dry Turning

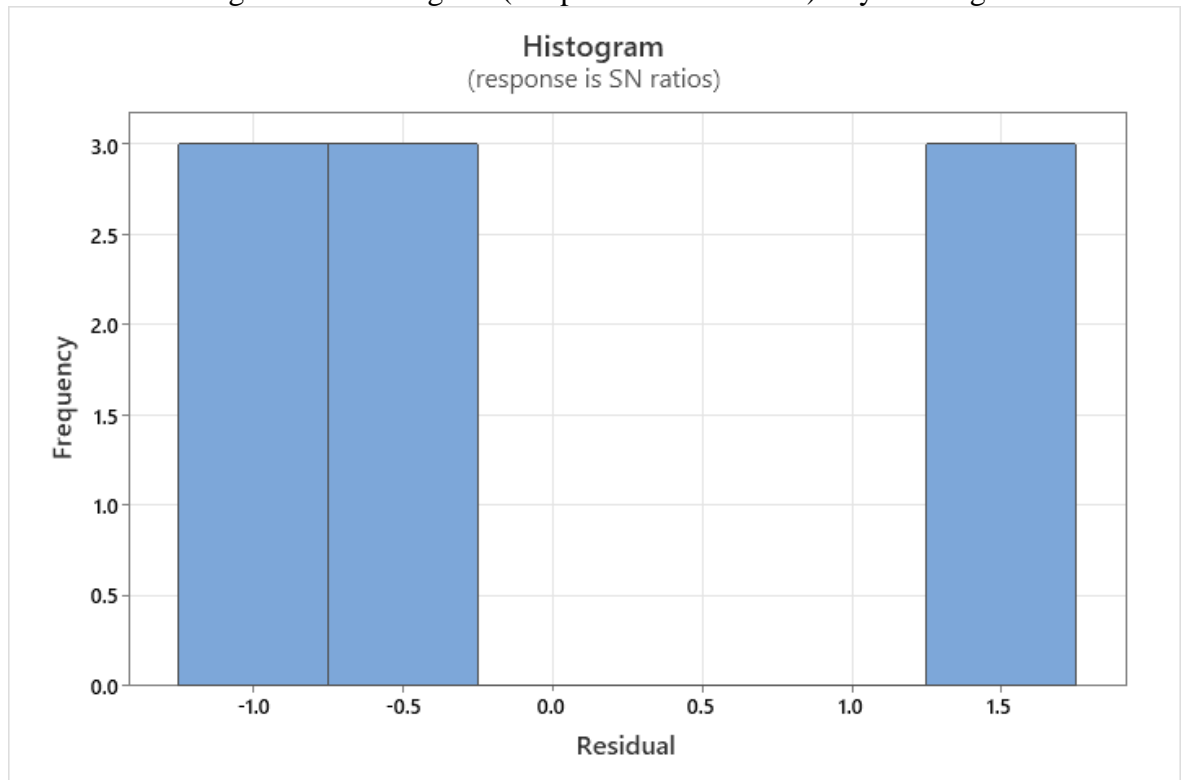


Figure 5.9 plots the histogram graph with frequency versus residual.

Table 5. 9: S/N Ratios of Performance Index (With Cutting Fluid)

Cutting Speed	Feed	Depth of Cut	Pi (With CF)	SNR
200	0.50	0.25	0.456	-22.4988
200	0.75	0.50	0.356	-18.9384
200	1.00	0.75	0.419	-2.7932
300	0.50	0.50	0.524	-12.4320
300	0.75	0.75	0.661	-15.9721
300	1.00	0.25	0.245	-12.5050
460	0.50	0.75	0.803	-1.0710
460	0.75	0.25	0.444	-14.0667
460	1	0.5	0.647	-11.0259

The calculated Signal to Noise ratio of Performance Index (With Cutting Fluid) are presented in Table 5.13. The Highest S/N ratio is at cutting speed 460rpm, feed 0.5, Depth of cut 0.75

Linear Model Analysis: SN ratios versus Cutting Speed, Feed, Depth of Cut

Estimated Model Coefficients for SN ratios

Table 5. 10: Estimated Model Coefficients for S/N Ratios of Wet Turning

Term	Coeff	SE Coeff	T	P
------	-------	----------	---	---

Constant	-6.3795	0.8727	-7.310	0.018
Cutting 200	-1.3876	1.2343	-1.124	0.378
Cutting 300	-0.7497	1.2343	-0.607	0.605
Feed 0.50	1.6077	1.2343	1.303	0.323
Feed 0.75	-0.1506	1.2343	-0.122	0.914
Depth of 0.25	-2.3043	1.2343	-1.867	0.203
Depth of 0.50	0.2647	1.2343	0.214	0.850

Analysis of Variance for SN ratios

Table 5. 11: Analysis of Variance for S/N Ratios of Wet Turning

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Cutting Speed	2	21.17	21.17	10.583	1.54	0.393	27.24
Feed	2	14.19	14.19	7.096	1.04	0.491	18.264
Depth of Cut	2	28.62	28.62	14.309	2.09	0.324	36.377
Residual Error	2	13.71	13.71	6.855			17.21
Total	8	77.69					

Model Summary

Table 5. 12: Model Summary (With Cutting Fluid)

S	R-Sq	R-Sq(adj)
2.3823	82.23%	28.94%

The ANOVA table for surface roughness is given in Table 5.15. It is observed that the R² value is 82.23 and hence confirms the consistency of the mathematical equation. From ANOVA table, it is noted that the highest contributing factor is the depth of cut with 36.377% of contribution

Response Table for Signal to Noise Ratios

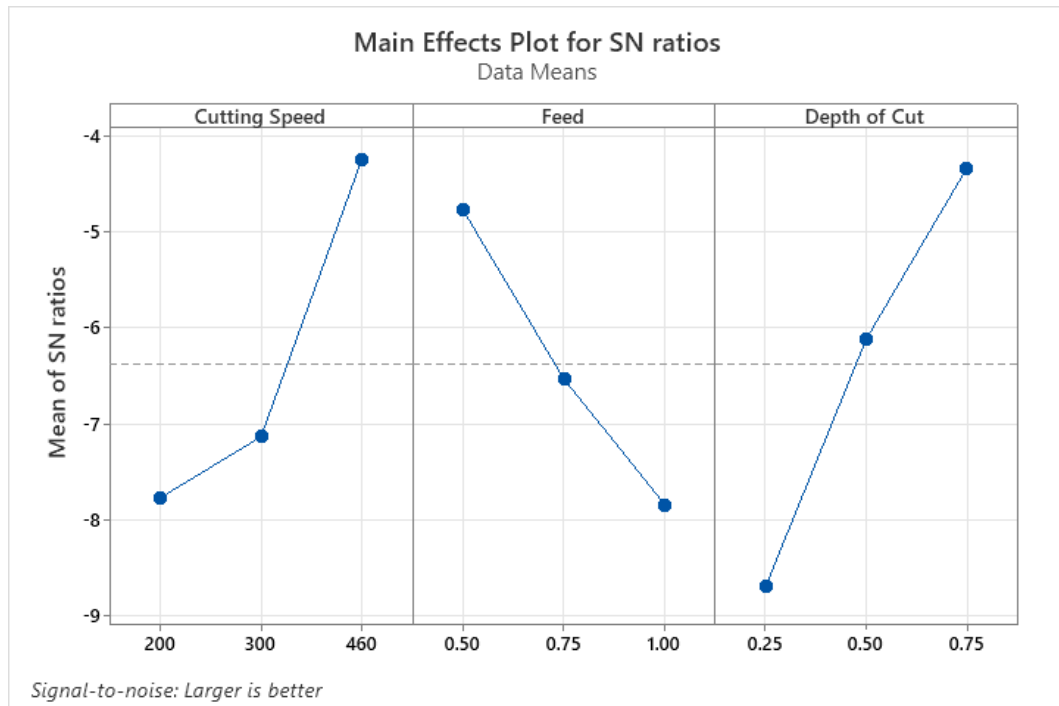
Larger is better

Table 5. 13: Response Table for Signal to Noise Ratios of Wet Turning

Level	Cutting Speed	Feed	Depth of Cut
1	-7.767	-4.772	-8.684
2	-7.129	-6.530	-6.115
3	-4.242	-7.837	-4.340
Delta	3.525	3.065	4.344
Rank	2	3	1

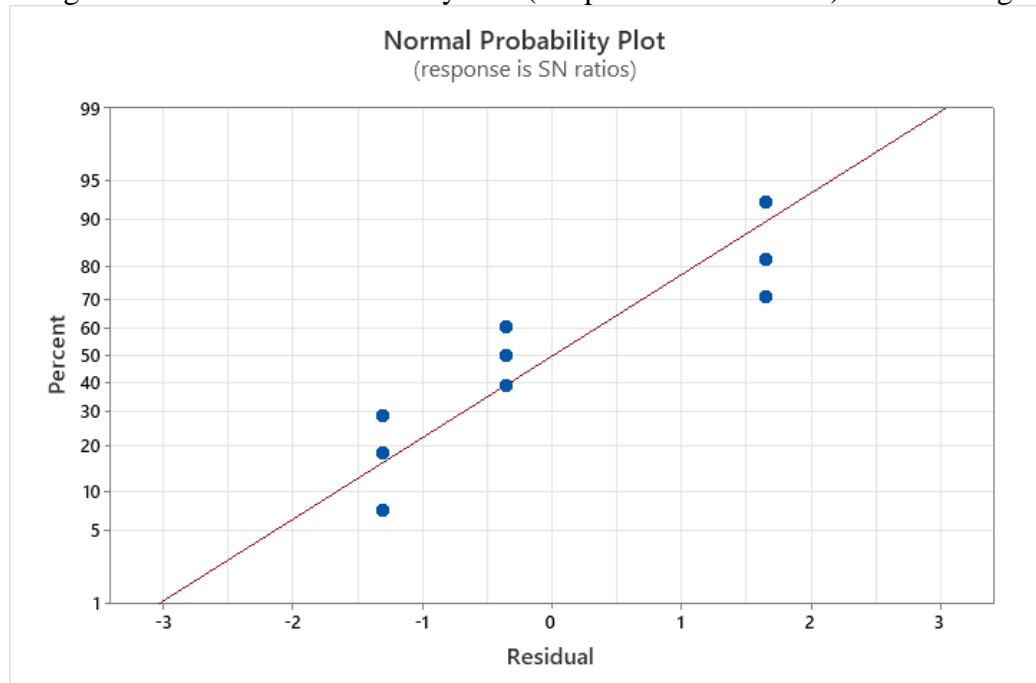
The response Table for signal to noise ratio for Surface roughness is shown in Table 5.17. It is observed that the depth of cut is the dominant parameter that affects surface roughness, material removal rate, temperature generated, shear angle followed by feed and depth of cut.

Figure 5. 102: Main Effects Plot for SN Ratios Wet Turning



The optimized process parameter range for surface roughness and flank wear are; Surface Roughness, cutting speed = 460 rpm, feed = 0.5mm/rev, depth of cut = 0.75. The main effects plot for S/N ratios roughness and Flank wear are shown in Figure 5.10.

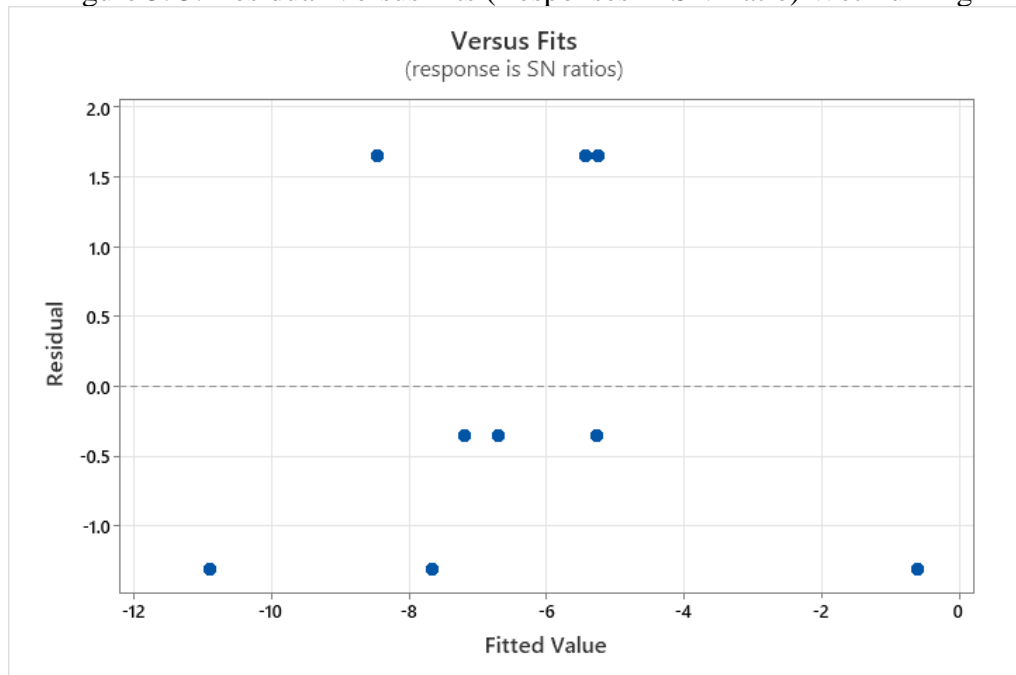
Figure 5. 11: Normal Probability Plot (Responses in SN Ratio) Wet Turning



The normal probability plot for surface roughness is shown in Figure 5.11. The middle line in the plot represents the expected probabilities among the distribution based on likelihood parameter estimates. The smooth curved line will be obtained if the distribution is good.

Here it is observed that all points fall closer to the middle line and satisfy the adequacy of the surface roughness optimization.

Figure 5. 3: Residual Versus Fits (Responses in SN Ratio) Wet Turning



The Figure 5.12 plots the residuals versus the fitted values.

Figure 5. 4: Histogram (Responses in SN Ratio) Wet Turning

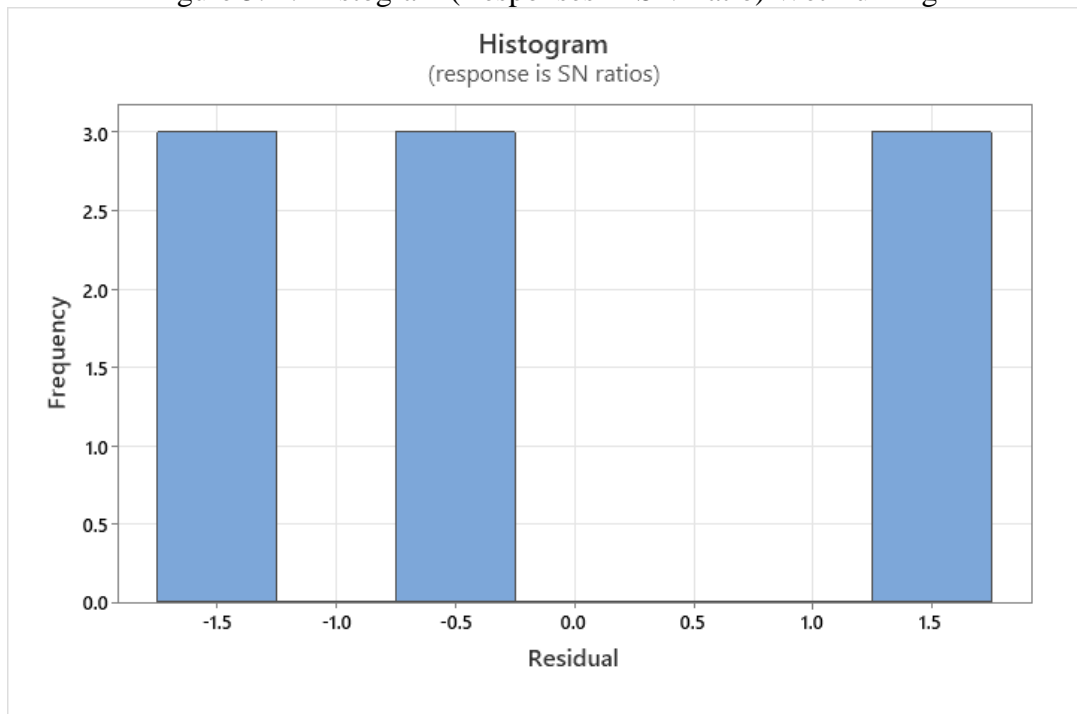


Figure 5.13 plots the histogram graph with frequency versus residual.

CHAPTER 6. CONCLUSION

The workpiece SS 304 has been machined in both wet and dry conditions with Tungsten Carbide Cutting Tool. TOPSIS method has been adopted for minimizing the 4 different output parameters to single output performance index. Taguchi method has been adopted for the design of experiments and results have been by maximizing the S/N ratio. The Performance index obtained from the TOPSIS is used for the Taguchi optimization technique.

In this study, the influence of cutting process parameters on surface roughness, temperature, shear angle, material removal rate for SS 304 with Tungsten carbide cutting tool during wet and dry turning process have been measured. Based on the results, it was found that cutting process parameters (cutting speed, feed and depth of cut) has influences on surface roughness, temperature, shear angle, material removal rate in wet and dry cutting condition. The following conclusion can be drawn:

- From the optimization plot, we got the best cutting parameters with Tungsten Carbide Cutting Tool and SS 304 Stainless Steel under Dry and Wet Conditions.
- Hence the optimal solution for shear angle is 75.243° , chip thickness ratio is 1.067 mm, cutting temperature 64°C , the surface roughness is $2.201\ \mu\text{m}$ and the material removal rate is $198.16\ \text{mm}^3/\text{min}$ is obtained when the SS 304 workpiece is machined at speed 460 rpm, feed 0.5 (mm/rev) and depth of cut 0.75 (mm) under Dry condition using Tungsten carbide tool for turning.
- Hence the optimal solution for shear angle is 69.64° , chip thickness ratio is 1.97, cutting temperature 54°C , the surface roughness is $2.989\ \mu\text{m}$ and the material removal rate is $212.314\ \text{mm}^3/\text{min}$ is obtained when the SS 304 workpiece is machined at speed 460rpm, feed 0.5(mm/rev), and depth of cut 0.75(mm) under Wet condition using carbide tool for turning.

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