Experimental Investigation on Effect of Drilling Parameters Using Taguchi Method and RSM

A Project report submitted

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MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the Project Report entitled "**EXPERIMENTAL INVISTIGATION ON EFFECT OF DRILLING PARAMETERS BY USING TAGUCHI AND RSM**" being submitted by JANA TUNISH SIVA SAI MALLIKARJUN (317126520022), PATNALA VIJAYA BHASKAR REDDY (317126520038), PENAGANTI SIVA PRASAD (317126520039), SAMEER AHMED (317126520045), KONA CHANDRA KIRAN YADAV (317126520029) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **MRS.B.KRISHNA PRAFULLA**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ABSTRACT

The present work focuses in the optimization of drilling process parameters using the Taguchi and RSM analysis. A number of experiments were done using the L18 orthogonal array on a CNC vertical machining center. The experiments were done on C45 steel using non-coated and coated HSS twist drills under wet conditions. The results of Taguchi and RSM analysis showed the toot type and speed are the predominant factors material removal rate and surface roughness respectively.

CHAPTER-1

INTRODUCTION

Hole making is among the most important operations in manufacturing. Drilling is a major and common of hole making process. Drilling is the cutting process of using a drill bit in a drill to cut or enlarge holes in solid materials, such as wood or metal. Different tools and methods are used for drilling depending on the type of material, the size of the hole, the number of holes. It is most frequently performed in material removal and is used as a preliminary step for many operations, such as reaming, tapping and boring. The cutting process in which a hole is originated or enlarged by means of a multipoint, fluted, end cutting tool. As the drill is rotated and advanced into the work piece, material is removed in the form of chips that move along the fluted shank of the drill. Below figure shows the drilling operation on to the work piece. In the below figure Drilling operation on the work piece Although long spiral chips usually result from drilling, adjustment of the feed rate can result in chip.

Drilling processes are widely used in the aerospace, aircraft, and automotive industries. Although modern metal-cutting methods have improved in the manufacturing industry, including electron beam machining, ultrasonic machining, electrolytic machining, and abrasive jet machining, conventional drilling still remains one of the most common machining processes. Worn drills produce poor quality holes and in extreme cases a broken drill can destroy an almost finished part. As it wears, cutting forces will increases, the temperature of the drill rises and this accelerates the physical and chemical processes associated with drill wear and therefore drill wears faster.

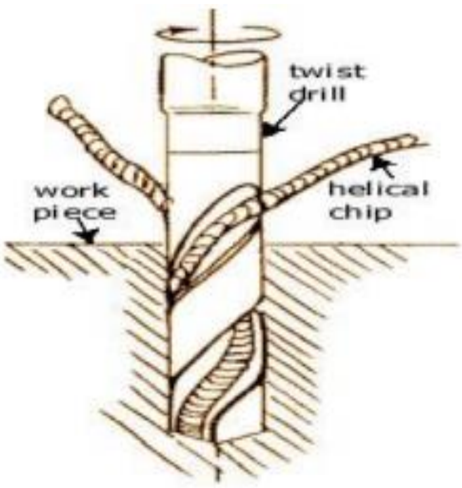


Figure.1 Drilling operation on the work piece

1.1.Drill Bit

Drill bits are cutting tools used to create cylindrical holes, almost always of circular cross-section. Drill bits come in many sizes and have many uses. Bits are usually connected to a mechanism, often simply referred to as a drill, which rotates them and provides torque and axial force to create the hole. The shank is the part of the drill bit grasped by the chuck of a drill. The cutting edges of the drill bit are at one end, and the shank is at the other. Drill bits come in standard sizes, described in the drill bit sizes article. A comprehensive drill bit and tap size chart lists metric and imperial sized drill bits alongside the required screw tap sizes.

1.2.Drill Bit Materials

Standard twist drills are fabricated using steel whose mechanical properties allow the drill bit to maintain its toughness, exhibit good abrasion resistance, and resist changes in harness as a result of the heat that is generated during the drilling process. Generally, the selection of the drill bit for a particular application should be made by giving consideration to the amount of heat that will be generated.

1. Carbon tool steels
2. High Speed steels
3. Cobalt High speed steels

1.2.1.Carbon Tool Steels

Carbon tool steels are used for applications where little heat is going to be generated. Both low and high carbon steels are both used for drill bits, but for different purposes. Soft low carbon steel cannot cut hard metals due to their poor tempers, but it can cut softwoods and plastics. They require sharpening to extend their lifespan. The primary bonus of low carbon steel is its relative inexpensiveness, especially when compared to some more exotic drill bit materials. High carbon steels have better tempers than low carbon steels, so they require less maintenance, such as sharpening, and hold their form and effectiveness longer. They can cut both woods and metals, and if available, are preferred to low carbon steels when cutting extremely hard woods.

1.2.2.High-Speed Steel

High-Speed Steel (HSS) is a preferred material for use in drill bits since it has a higher red hardness and improved wear resistance. These properties allow for drilling at higher operating speeds and into harder materials. The friction created by high-speed turning can raise temperatures dramatically, but HSS is designed to operate at these higher speeds. HSS can function at normal temperatures, as well, but only at a level equal to standard carbon steel. HSS can also take coatings, such as titanium nitride, which give the drill bit better lubricity, decreasing friction and helping to extend the bit’s life.

1.2.3Cobalt High-Speed Steel

Cobalt High-Speed Steel (HSS) drill bits have added Cobalt which gives the material a higher red hardness than standard HSS. This additional hardness permits these drill bits to be used for drilling materials that have a hardness of Rockwell 38C or greater such as treated stainless steel, cast iron, or titanium. They are also capable of being utilized at higher cutting speeds than conventional HSS and exhibit superior abrasion resistance.

1.3.Coatings and Treatments:

1.3.1.Titanium

Titanium is a corrosion-resistant metal, and in the form of titanium nitride, is used as a coating applied to HSS drill bits to give them very high levels of surface hardness. This characteristic allows titanium-coated drill bits to be used to drill tough materials and last up to 6 times longer than standard HSS bits. This longevity makes it attractive for use in repetitive, large runs. It is a very versatile drill bit coating, and it can cut a broad variety of surfaces, including many types of steel and iron, as well as softer materials including wood, drywall, and plastic. The addition of titanium nitride also reduces friction between the bit and the workpiece, significantly reducing heat and therefore wear.

1.3.2.Titanium nitride (TiN) Coated Drills

It is a hard ceramic material coated to HSS drills. Coated drill tolls are used to drill metal workpieces, since it has good mechanical properties. Coating HSS drill bit improves self-lubricating and hardness properties. The cutting tool life can be increased by two or more times to the HSS drills. TiN is very hard and inert material; thin film coatings is applied to metal parts. Titanium nitride is a combination of toughness, hardness and inertness. Physical vapor deposition (PVD) system is the environmentally safe coating method, for coating thin film on HSS tool. Applying TiN coating to metals improves surface characteristics. The coated TiN has gold colour with ultra- hard material. It has very high chemical resistance which will not corrode during drilling. It has high temperature withstand capacity up to 6000c, and non-toxic hence used for food processing equipment and medical surgicals. The coating is up to 3 micrometres thick. It has an wonderful bond to base material that will not erupt, chip off or flake. TiN coated tools have 3-10 times long life capacity than uncoated tools.

1.3.3.Titanium Aluminium Nitride (TiAlN)

Titanium nitride develops thin film coating of Titanium Aluminium nitride (TiAlN), which offers very high temperature resistance than TiN. It has good hardness property at high temperature, and hence used in high temperature which exceeds limit of TiN. The coating is done by developing thin layer of aluminium oxide ceramic. It is a hard ceramic material coated to HSS drills. Coated drill tolls are used to drill metal workpieces, since it has good mechanical properties. Coating HSS drill bit improves self-lubricating and hardness properties. The cutting tool life can be increased by two or more times to the HSS drills. TiAlN coating can withstand higher temperature up to 8000C, it has good oxidation resistance, low in friction and hard coating. TiAlN used in high temperature applications, it is a complex structure of TiN and AlN which bond in crystalline matrix. It has 3-6 micrometre coating thickness, and has longer tool life of 3 to 10 times than uncoated tools. It has a wonderful bond to base material that will not erupt, chip off or flake. Physical vapor deposition (PVD) system is the environmentally safe coating method, for coating thin film on HSS tool.

1.3.4.Black oxide

Black oxide is not a coating but rather a heat treatment process that is applied to HSS which reduces friction and increases the life of the drill bit by some 50% over that of standard HSS. They are created by heating HSS to 950 degrees F to add corrosion and rust resistance. These bits can be used for carbon steels, alloy steels, as well as softer materials such as wood, plastics, PVC, drywall as well as softer metals such as copper and aluminum.

1.3.5.Zirconium Coating

While not a primary material for drill bits, zirconium-coated metals function very well for drill bits. The zirconium nitride coating can increase strength for hard but brittle materials, like steel. The makeup of the zirconium also decreases friction for improved precision drilling.

1.3.6.Diamond

Some steel bits are embedded with diamond dust; these are available as either hollow core bits or as smaller blunt nose bits with no open space in the middle. The diamond enables them to cut through materials like glass, gemstones, ceramic, bone, and stone. However, they should not be used on ferrous metals.

Classification Of Drill Bits

- Twist drill
- Counter bore drill
- Counter sink drill
- Flat bottom boring

1.4.Twist Drills

General Description: Twist drill bits are the most common type of drill bit and are used for everyday drilling in all types of material. They are also the most confusing due to the sheer number of size, tip, and material specifications.

Length Designations: The length of a twist drill has much to do with its rigidity - a shorter bit will be stronger and less likely to wander or break but may not have the reach needed for all jobs. Twist drill bits for use in automated machinery have an actual length specification (e.g. 4-1/2") while most (not all) twist drills for use in portable drills are graduated length and use a name to specify the length range:

- **Jobber Length:** These are the most common twist drills and are a good compromise between length and strength. Jobber drills vary in length according to their diameter and typically have a flute length of 9-14 times the cutting diameter, i.e. a 1/2" jobber drill has a flute length of 4-1/2" (nine times the diameter) with smaller drills having a larger ratio.

- **Mechanics Length:** Shorter than jobber drills, mechanics length drills are named as such because they fit into tighter spaces and are less likely to break while still allowing a reasonable flute length.
- **Screw Machine Length:** Also called "stubby length", these are the shortest common drill bits. Originally designed for screw machines, many people prefer these due to their high strength and added working clearance.
- **Extra Length:** These are extra long drill bits (up to 18") with flutes extending the entire length of the bit. Extra length drills can be very fragile and easily broken so it's usually best to drill as deep as possible with a jobber or shorter bit before switching to an extra length drill bit.
- **Aircraft Extension:** Similar in length to extra length bits, aircraft extension drill bits emphasize reach over cutting depth and have a shorter flute length (about the same as a jobber drill). This makes the bit much stronger and less susceptible to bending and breaking.
- **Silver and Deming:** More than a length specification, Silver and Deming drill bits are 6" long with a 3" flute length and a 1/2" diameter shank. All Silver and Deming bits are over 1/2" cutting diameter, ranging from 33/64" to 1-1/2", and are primarily intended for use in a drill press.
- **Size Designations:** Common twist drills for use in portable drills, etc. are available in fractional inch, wire sizes, letter sizes, and metric decimal millimeter. Twist drills for use in automated machinery are only available in fractional inch and decimal millimeter.

1.4.1.Tip Styles

Twist drill bits are available with different tip styles to suit various applications as outlined below:

Conventional Drill Point: This is the most common tip style as seen on everyday general-purpose drills. The tip angle is usually 118 degrees but can vary from 90° to high angle "Plexi-point" for use in acrylics. Conventional drill point drills are the most economical and are easily re-sharpened. Suitable for wood, non-ferrous metals and mild steel.

Split Drill Point: This is an advanced drill point that prevents walking and provides improved penetration with less effort. Available in 118 (or) 135-degree angles, split point drill bits are better for drilling in curved surfaces or in alloy steels. They are more expensive and more difficult to re-sharpen than standard drill points.

V-Point: This is a special high angle tip used on drill bits for automated wood boring machines. V-point drills are used to create thru-holes in sheet stock for dowels or other assembly hardware.

Brad Point: Designed for creating blind holes in wood and other soft materials for shelf pins, dowels, etc. Bradpoints are also used for thru-holes in CNC applications where a conventional drill point would penetrate the table below the panel. Bradpoints have spurs on the outer edges to prevent splintering and chipping of the surface material as well as a center spur to prevent walking as the bit penetrates the surface.

Fishtail Point: These special drill points form a reverse "V" in the tip and are designed for drilling into a surface at an angle without walking. They are commonly used as center drills in counterbores for furniture assembly where panels must be joined at right angles.

Taper Point: These drill bits have a very large taper, extending far up the drill which creates a tapered hole. Primarily used for old style wood screws.

Flute Styles: Most twist drills have flutes to evacuate the chips at an unspecified angle, and are suitable for the majority of applications. Some specialty twist drills may be designated as "High Helix", "Fast Spiral" or "Low Helix", "Slow Spiral" for specific applications requiring higher or lower spindle speeds or feed rates.

Shank Styles: Twist drill bits designed for use in automated machinery have fixed diameter (usually 1/2" or 10mm) shanks, threaded shanks, or specialty shanks designed for certain machines. General purpose twist drills for use in portable drills have shanks the same diameter as the bit size (up to a certain diameter), larger diameter bits incorporate a reduced shank (either 1/4", 3/8" or 1/2") to fit into a standard drill chuck. Some bits have 3 flats on the shank to prevent spinning under high torque loads. Others have 1/4" hex shanks for use in a portable drill with a hex bit holder.

Materials: General purpose twist drills for use in portable drills are available in different grades of high-speed steel as well as cobalt steel and solid carbide. Twist drill bits for automated machinery are available in carbon steel, high speed steel, carbide tipped, and solid carbide.

Coatings: General purpose drill bits are available with black oxide, bronze oxide, a combination of black and bronze oxide, and TiN coatings. Twist drills for automated machinery on our site are primarily for use in wood or plastics and are not coated.

1.4.2.Counterbore Drill Bits

General Description: Counterbore drill bits create a flat bottom blind hole with a smaller diameter center hole that penetrates through the material. The purpose of a counterbore is usually to conceal the fastener head (by covering the hole) or provide a recess to prevent the fastener from protruding above the surface of the material being drilled. Counterbores on our site are designed for use in wood or plastics and are not intended for counterboring steel.

Tip Styles: The cutting tip of a counterbore drill consists of one or more flat blades extending from the center drill to the outer edge. Counterbores are available with or without spurs (teeth) at the outer diameter of the bit. Counterbores with spurs on the outer edge prevent chipping and splintering on wood or laminated surfaces.

Flute Styles: Some counterbores do not have flutes (except for the center drill) and simply shave away the material, others are designed similar to a twist drill with no tip angle and a replaceable center drill.

Shank Styles: Counterbores for use in Hand held Drills typically clamp on to a standard twist drill and therefore have a straight shank the same diameter as the center drill**.** Counterbores for use in automated machinery have fixed diameter (usually 1/2" or 10mm) shanks, threaded shanks, or specialty shanks designed for certain machines.

Materials: Counterbores are available in Carbon Steel, High Speed Steel, or Carbide Tipped

Coatings: Counterbores on our site do not contain special coatings.

1.4.3.Countersink Drill Bits

General Description: Countersink drill bits create a tapered surface hole with a smaller center hole that penetrates through the material (some are available without a center drill for countersinking existing holes). The purpose of a countersink is to allow a tapered head fastener to sit flush with the surface of the material. Countersinks on our site are designed for use in wood or plastics and are not intended for counterboring steel.

Tip Styles: The cutting tip of a countersink drill consists of two or more flat blades extending from the center drill to the outer edge. Countersinks are made with angles from 60 to 120 degrees but those on our site are typically 82 or 90 degrees. For wood use many times the manufacturer does not specify the angle.

Flute Styles: Some countersinks do not have flutes (except for the center drill) and simply shave away the material, others are designed similar to a twist drill with a replaceable center drill.

Shank Styles: Countersinks for use in hand-held drills typically clamp on to a standard twist drill and therefore have a straight shank the same diameter as the center drill (some have 1/4" hex shanks for hand use in a bit holding screwdriver). Countersinks for use in automated machinery have fixed diameter (usually 1/2" or 10mm) shanks, threaded shanks, or specialty shanks designed for certain types of machines.

Materials: Countersinks are available in Carbon Steel, High Speed Steel, or Carbide Tipped

Coatings: Countersinks on our site do not contain special coatings.

1.4.4.Flat Bottom Boring Bits

General Description: Flat bottom boring bits are similar to counterbores but do not include a center drill. These bits are designed to drill flat bottom blind holes for European style hinges, etc. Flat bottom boring bits are also used for drilling large diameter thru-holes without the plug that is typical when using a hole saw. These thru-hole bits are used for locks, door knobs, wiring holes, etc. Flat bottom boring bits on our site are designed for use in wood or plastics and are not intended for use in steel.

Common types of Flat Bottom Boring Bits include:

1. Forstner Bits
2. Three Wing Drills
3. Door Hinge Bits
4. Mortising Bits
5. Spade Bits

Tip Styles: The cutting tip of a flat bottom boring drill consists of one or more flat blades extending from the center to the outer edge. Flat bottom boring bits are available with or without spurs (teeth) at the outer diameter of the bit. Bits with spurs on the outer edge prevent chipping and splintering on wood or laminated surfaces. Some flat bottom boring bits also include a center spur to keep the bit from walking during the initial cut - Spade bits are a good example.

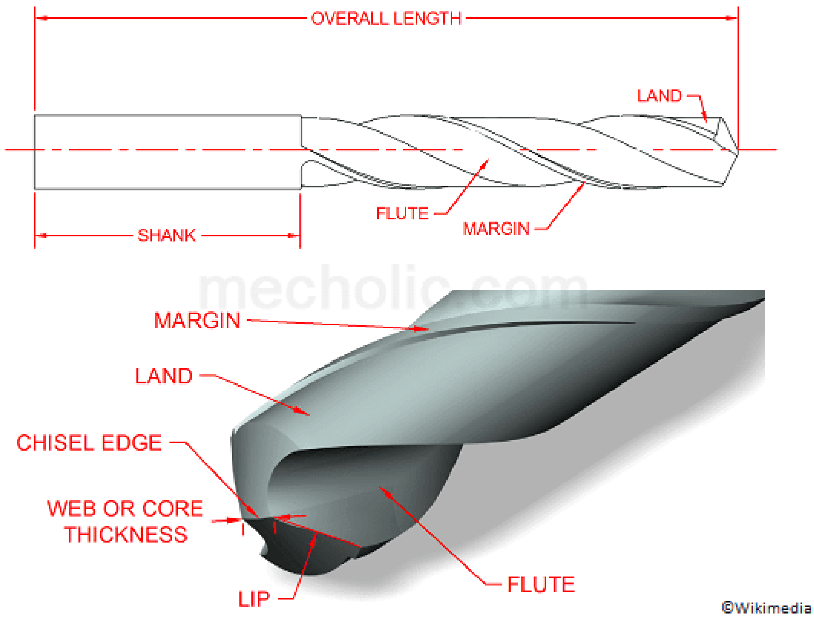
Flute Styles: Large flat bottom boring bits do not have flutes, they consist of only the cutting surface and the chips remain in the hole until the bit is removed.

Shank Styles: Most large flat bottom boring bits have a fixed size hexagonal shank. The hex shank prevents the bit from spinning in the chuck under excessive loads.

Materials: Flat bottom boring bits are available in Carbon Steel, High Speed Steel, or Carbide Tipped.

Coatings: Flat bottom boring bits on our site do not contain special coatings.

1.4.5.Twist drill Nomenclature



Twist drill is a cutting tool comprised of cutting point at tip of a shaft with helical cutting edge. The various elements of twisting drills are described below.

Body: It is the main parts of the tool, it extend from the drill shank to the tip of tool.

Shank: It is the cylindrical portion of the drill that held in holding device. The shank may be straight or tapered. Hex shank drill bits are also available. The parallel shanks are provided in small tool bits. It is held in the machine by chucks. The larger size drills are provided tapered shank. It carries a tang at the end of the shank to ensure proper grip between the drill bit and driving machine.

Tang: It is the flattened end of the tapered shank, which fit into the driving slot in a socket. It ensures the positive drive from the drill spindle.

Neck: The portion of reduced diameter in between the body and shank

Margin: The part of the body which do not cut away. This narrow extension through the entire body provides clearance between drill and work material. A double margin drill bit have two margin instead of one.

Dead center or chisel edge: It is the point where two cutting edge meets at the extreme tip. It should always be lie in the axis of twist drill.

Flutes: It is the grooves in twist drill, which provides lip or cutting edge.

Flank: surface of drill, which extends behind the lip to the flute.

Lip: It is the cutting edge formed at the intersection of flank and flute.

According to the tip of drill bit it may classified in to Split point drill bit, Pilot point drill bit and Brad point drill bits.

1.4.6.Advantages and Disadvantages of Twist Drills

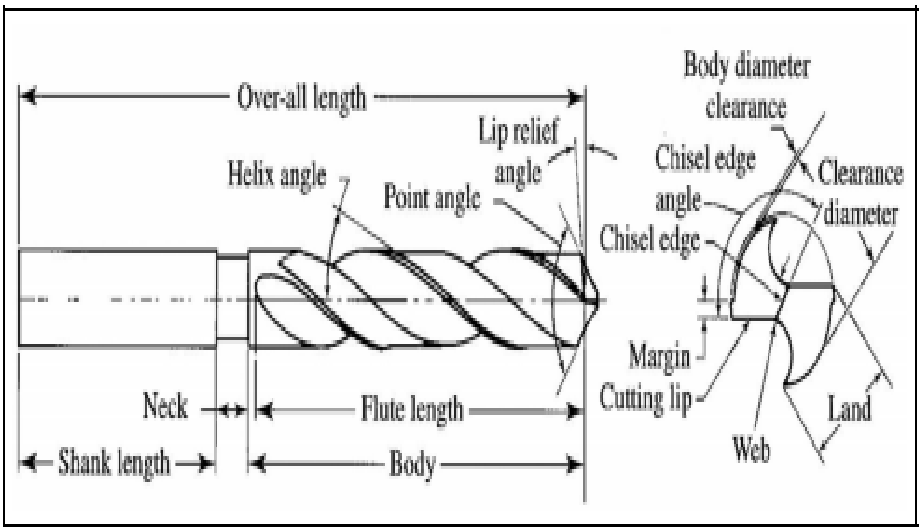
Advantages

1. To drill a hole of same depth and diameter twist drill required less power when compared to the other type of drills.
2. Considerable time saving because heavier feed and speed can be employed within safety limit
3. Tool life is good; one twist drill can be used for a long time without frequent regrinding.
4. The chips and cuttings are automatically driven out of the hole through the flute of the twist drill

Disadvantages

1. Finishing is not good enough
2. Small diameter twist drill prone to breaking
3. Regrinding of lips is a delicate process
4. Excessive heating may change the property tool material. Re-tempering of the drill without special facilities is not satisfactory.

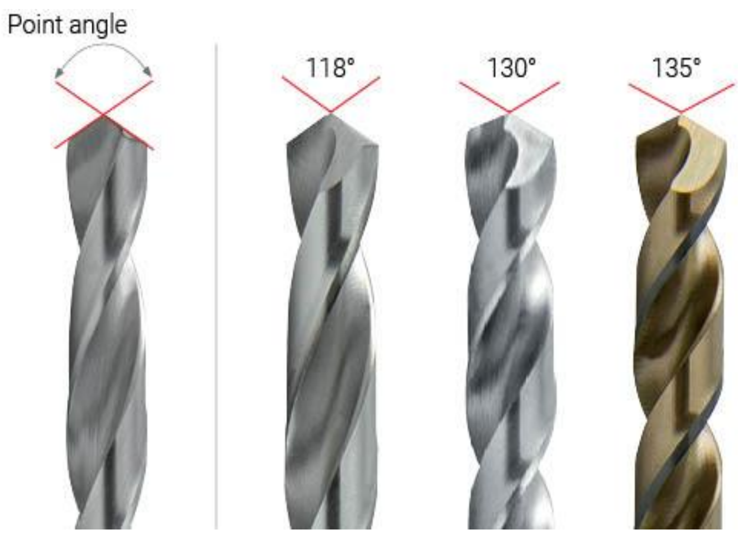
1.5.Twist Drill Geometry



The complexity of the geometry of a twist drill requires careful design consideration. The cutting dynamics, drilling forces and tool wear strongly depend on the drill dimensions and geometry. The machine tool requires much more energy and power when its cutting tool is poorly designed, in addition to tendency of damage on the machine.

1.5.1.Point angle

The point angle is located on the head of the twist drill. The angle is measured between the two main cutting edges at the top. A point angle is necessary to center the twist drill in the material.



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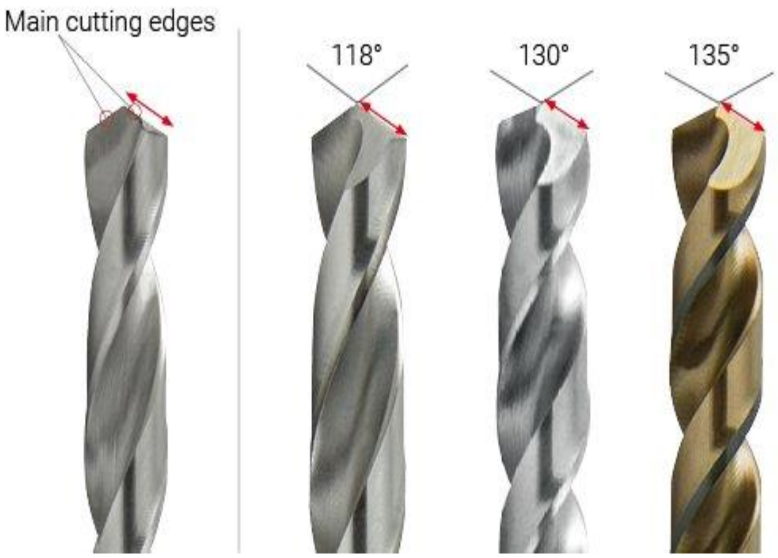
The smaller the point angle, the easier the centering in the material. This also reduces the risk of slipping on curved surfaces.

The larger the point angle, the shorter the tapping time. However, a higher contact pressure is required and centering in the material is harder.

Geometrically conditioned, a small point angle means long main cutting edges, whereas a large point angle means short main cutting edges.

1.5.2.Main cutting Edges

The main cutting edges take over the actual drilling process. Long cutting edges have a higher cutting performance compared to short cutting edges, even if the differences are very small.



The twist drill always has two main cutting edges connected by a cut chisel edge.

1.5.3.Cut Chisel Edge

The cut chisel edge is located in the middle of the drill tip and has no cutting effect. However, it is essential for the construction of the twist drill, as it connects the two main cutting edges. The cut chisel edge is responsible for entering the material and exerts pressure and friction on the material. These properties, which are unfavourable for the drilling process, result in increased heat generation and increased power consumption.

However, these properties can be reduced by so-called "thinning".

1.5.4.Point cuts and Point Thinning

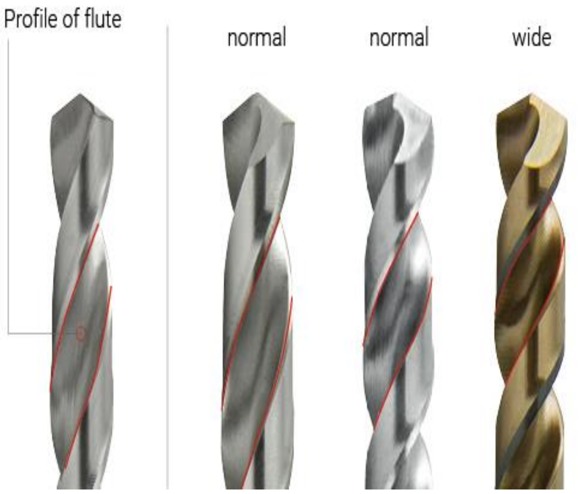
The point thinning reduces the cut chisel edge at the top of the twist drill. The thinning results in a substantial reduction of the friction forces in the material and thus a reduction of the necessary feed force. This means that thinning is the decisive factor for centering in the material. It improves the tapping.

The various point thinning are standardised in DIN 1412 shapes. The most common shapes are the helical point (shape N) and split point (shape C).

1.5.5.Profile of flute (groove profile)

Due to its function as a channel system, the profile of flute promotes chip absorption and removal.

The wider the groove profile, the better the chip absorption and removal.

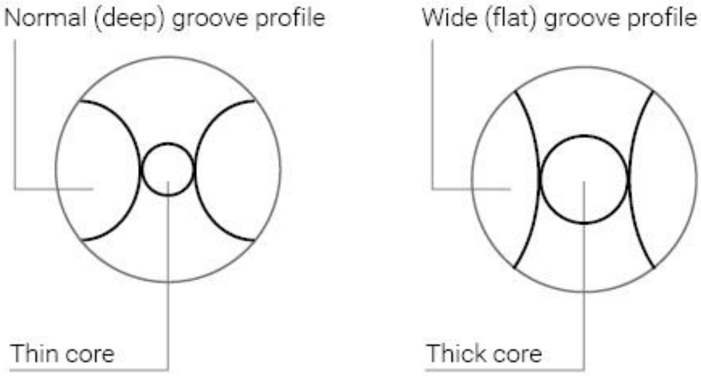


Poor chip removal means a higher heat development, which in return can lead to annealing and ultimately to breakage of the twist drill.

Wide groove profiles are flat, thin groove profiles are deep. The depth of the groove profile determines the thickness of the drill core. Flat groove profiles allow large (thick) core diameters. Deep groove profiles allow small (thin) core diameters.

1.5.6.Core

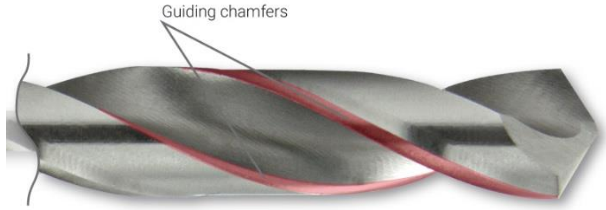
The core thickness is the determining measure for the stability of the twist drill. Twist drills with a large (thick) core diameter have higher stability and are therefore suitable for higher torques and harder materials. They are also very well suited for use in hand drills as they are more resistant to vibrations and lateral forces.

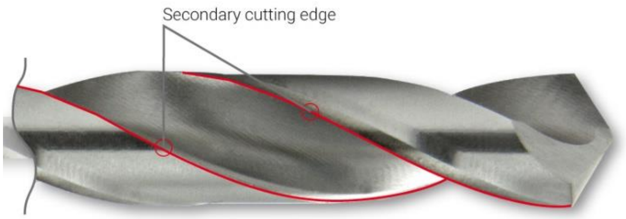


In order to facilitate the removal of chips from the groove, the core thickness increases from the drill tip to the shank.

1.5.7.Guiding Chamfers and Secondary Cutting Edges

The two guide chamfers are located at the flutes. The sharply ground chamfers work additionally on the side surfaces of the borehole and support the guidance of the twist drill in the drilled hole. The quality of the borehole walls also depends on the guide chamfers properties.

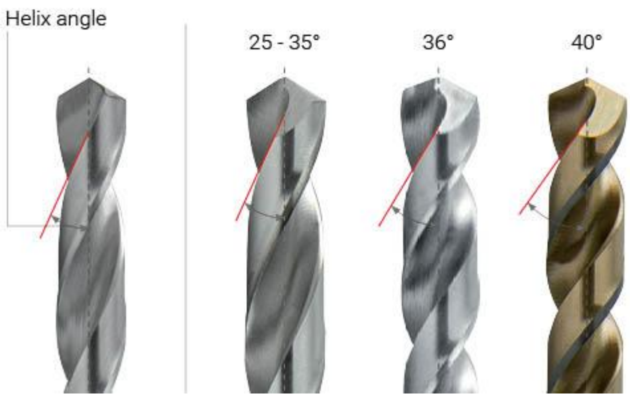




The secondary cutting edge forms the transition from guide chamfers to groove profile. It loosens and cuts chips that have got stuck to the material. The length of the guide chamfers and secondary cutting edges depend largely on the helix angle.

1.5.8.Helix angle (spiral angle)

An essential feature of a twist drill is the helix angle (spiral angle). It determines the process of chip formation. Larger helix angles provide effective removal of soft, long-chipping materials. Smaller helix angles, on the other hand, are used for hard, short-chipping materials.



Twist drills that have a very small helix angle (10° - 19°) have a lengthy spiral. In return, twist drills with a large helix angle (27° - 45°) have a rammed (short) spiral. Twist drills with a normal spiral have a helix angle of 19° - 40°

1.5.9.Lip Relief Angle

The lip angle determines the amount of support provided to the cutting edge. A greater lip angle will cause the bit to cut more aggressively under the same amount of point pressure as a bit with a smaller lip angle. Both conditions can cause binding, wear, and eventual catastrophic failure of the tool. The proper amount of lip clearance is determined by the point angle. A very acute point angle has more web surface area presented to the work at any one time, requiring an aggressive lip angle, where a flat bit is extremely sensitive to small changes in lip angle due to the small surface area supporting the cutting edges.

1.6.CNC Machining

The term CNC stands for 'computer numerical control', and the CNC machining definition is that it is a subtractive manufacturing process which typically employs computerized controls and machine tools to remove layers of material from a stock piece—known as the blank or workpiece—and produces a custom-designed part. This process is suitable for a wide range of materials, including metals, plastics, wood, glass, foam, and composites, and finds application in a variety of industries, such as large CNC machining, machining of parts and prototypes for telecommunications, and CNC machining aerospace parts, which require tighter tolerances than other industries. Note there is a difference between the CNC machining definition and the CNC machine definition- one is a process and the other is a machine. A CNC machine is a programmable machine that is capable of autonomously performing the operations of CNC machining.

1.6.1.Overview of CNC Machining Process

Evolving from the numerical control (NC) machining process which utilized punched tape cards, CNC machining is a manufacturing process which utilizes computerized controls to operate and manipulate machine and cutting tools to shape stock material—e.g., metal, plastic, wood, foam, composite, etc.—into custom parts and designs. While the CNC machining process offers various capabilities and operations, the fundamental principles of the process remain largely the same throughout all of them. The basic CNC machining process includes the following stages:

1. Designing the CAD model
2. Converting the CAD file to a CNC program
3. Preparing the CNC machine
4. Executing the machining operation

1.6.2. Types of CNC Machining Operations

CNC machining is a manufacturing process suitable for a wide variety of industries, including automotive, aerospace, construction, and agriculture, and able to produce a range of products, such as automobile frames, surgical equipment, airplane engines, gears, and hand and garden tools. The process encompasses several different computer-controlled machining operations—including mechanical, chemical, electrical, and thermal processes—which remove the necessary material from the workpiece to produce a custom-designed part or product. While chemical, electrical, and thermal machining processes are covered in a later section, this section explores some of the most common mechanical CNC machining operations including:

1. Drilling
2. Milling
3. Turning

1.6.3. Computer Numerical Control) CNC Drilling

Computer Numerical Control (CNC) Drilling is commonly implemented for mass production. The drilling machine, however, is often a multi-function machining center that also mills and sometimes turns. The largest time sink for CNC drilling is with tool changes, so for speed, variation of hole diameters should be minimized. The fastest machines for drilling varying hole sizes have multiple spindles in turrets with drills of varying diameters already mounted for drilling. The appropriate drill is brought into position through movement of the turret, so that bits do not need to be removed and replaced. A turret-type CNC drilling machine is shown below.
A variety of semi-automated drilling machines are also used. An example is a simple drill press which, on command, drills a hole of a set depth into a part set up beneath it. In order to be cost-effective, the appropriate type of CNC drilling machine needs to be applied to a particular part geometry. For low-volume jobs, manual or semi-automated drilling may suffice. For hole patterns

with large differences in sizes and high volume, a geared head is most appropriate. If holes are close to each other and high throughput is desired, a gearless head can locate spindles close together so that the hole pattern can be completed in one pass.

1.6.4.CNC Drilling Equipment

Drilling employs rotating drill bits to produce the cylindrical holes in the workpiece. The design of the drill bit allows for the waste metal—i.e., chips—to fall away from the workpiece. There are several types of drill bits, each of which is used for a specific application. Types of drill bits available include spotting drills (for producing shallow or pilot holes), peck drills (for reducing the amount of chips on the workpiece), screw machine drills (for producing holes without a pilot hole), and chucking reamers (for enlarging previously produced holes).

Typically, the CNC drilling process also utilizes CNC-enabled drill presses, which are specifically designed to perform the drilling operation. However, the operation can also be performed by turning, tapping, or milling machines.

1.6.5.Overview of CNC Programming

CNC machines are very accurate and powerful industrial robots developed jointly by Mr. John Parsons, IBM and Massachusetts Institute of Technology Servomechanism Laboratory in the 1950's. Most CNC machine tools use a language set by the Electronics Industry Association (EIA) in the 1960's. The official name of this language is RS-274D, but everyone refers it "G-code" or "G&M Code" because many of the words of this language begin with the letters G or M. While many of the words used by different CNC machines are the same, there are differences between makes and models. This is due in part to machines having different configurations and options. For example, a machine with a chip conveyor will have words to turn the conveyor on and off, while a machine without a conveyor does not. So, while RS-274D is a standard, it is not rigid or enforced. Always refer to the machine documentation for the exact words and syntax for your CNC machine. Most machines have a vocabulary of at least a hundred words, but only about thirty that are used often. These thirty or so words are best memorized because they appear in almost every CNC program and knowing them helps you work more efficiently. The G-code language was developed when machine controls had very little memory. It was therefore designed to be as compact as possible. While at first this language may seem arcane, the modern machine tool language is the safest and most efficient way yet devised to control machine tool motion. G&M codes, along with coordinates and other parameters, comprise what is called a CNC program.

1.6.6.CNC Language and Structure

CNC programs list instructions to be performed in the order they are written. They read like a book, left to right and top-down. Each sentence in a CNC program is written on a separate line, called a Block. Blocks are arranged in a specific sequence that promotes safety, predictability and readability, so it is important to adhere to a standard program structure. Typically, blocks are arranged in the following order:

1) Program Start
2) Load Tool
3) Spindle On
4) Coolant On
5) Rapid to position above part
6) Machining operation
7) Coolant Off
8) Spindle Off
9) Move to safe position
10) End program

The steps listed above represent the simplest type of CNC program, where only one tool is used and one operation performed. Programs that use multiple tools repeat steps two through nine for each.

1.6.7.Program Format

The program in Figure 1 below machines a square contour and drills a hole.

Block	Description	Purpose
%	Start of program.	Start Program
O0001 (PROJECT1)	Program number (Program Name).	
(T1 0.25 END MILL)	Tool description for operator.	
N1 G17 G20 G40 G49 G80 G90	Safety block to ensure machine is in safe mode.	
N2 T1 M6	Load Tool #1.	Change Tool
N3 S9200 M3	Spindle Speed 9200 RPM, On CW.	
N4 G54	Use Fixture Offset #1.	Move To Position
N5 M8	Coolant On.	
N6 G00 X-0.025 Y-0.275	Rapid above part.	
N7 G43 Z1. H1	Rapid to safe plane, use Tool Length Offset #1.	
N8 Z0.1	Rapid to feed plane.	
N9 G01 Z-0.1 F18.	Line move to cutting depth at 18 IPM.	
N10 G41 Y0.1 D1 F36.	CDC Left, Lead in line, Dia. Offset #1, 36 IPM.	Machine Contour
N11 Y2.025	Line move.	
N12 X2.025	Line move.	
N13 Y-0.025	Line move.	
N14 X-0.025	Line move.	
N15 G40 X-0.4	Turn CDC off with lead-out move.	
N16 G00 Z1.	Rapid to safe plane.	
N17 M5	Spindle Off.	Change Tool
N18 M9	Coolant Off.	
(T2 0.25 DRILL)	Tool description for operator.	
N19 T2 M6	Load Tool #2.	
N20 S3820 M3	Spindle Speed 3820 RPM, On CW.	
N21 M8	Coolant On.	Move To Position
N22 X1. Y1.	Rapid above hole.	
N23 G43 Z1. H2	Rapid to safe plane, use Tool Length Offset 2.	
N24 Z0.25	Rapid to feed plane.	
N25 G98 G81 Z-0.325 R0.1 F12.	Drill hole (canned) cycle, Depth Z-.325, F12.	Drill Hole
N26 G80	Cancel drill cycle.	
N27 Z1.	Rapid to safe plane.	
N28 M5	Spindle Off.	End Program
N29 M9	Coolant Off.	
N30 G91 G28 Z0	Return to machine Home position in Z.	
N31 G91 G28 X0 Y0	Return to machine Home position in XY.	
N32 G90	Reset to absolute positioning mode (for safety).	
N33 M30	Reset program to beginning.	
%	End Program.	

Figure 1: Simple CNC Program

1.6.8.Alphabetic & Special Character Address Codes

Every letter of the alphabet is used as a machine address code. In fact, some are used more than once, and their meaning changes based on which G-code appears in the same block. Codes are either modal, which means they remain in effect until cancelled or changed, or non-modal, which means they are effective only in the current block. The table below lists the most common address codes. A complete list is included in Appendix B, G-M Code Reference.

Code	Meaning
A	Rotation about X-axis.
B	Rotation about Y-axis.
C	Rotation about Z-axis.
D	Cutter diameter compensation (CDC) offset address.
F	Feed rate.
G	G-Code (preparatory code).
H	Tool length offset (TLO).
I	Arc center X-vector, also used in drill cycles.
J	Arc center Y-vector, also used in drill cycles.
K	Arc center Z-vector, also used in drill cycles.
M	M-Code (miscellaneous code).
N	Block Number.
O	Program Number.
P	Dwell time.
Q	Used in drill cycles.
R	Arc radius, also used in drill cycles.
S	Spindle speed in RPM.
T	Tool number.
X	X-coordinate.
Y	Y-coordinate.
Z	Z-coordinate.

Table 3: Common Alphanumeric Address Codes

1.6.9.G-Codes

Codes that begin with G are called preparatory words because they prepare the machine for a certain type of motion. The most common G-codes are shown in Table 1 and a complete list and their meaning is included in Appendix B, G-M Code Reference.

Code	Meaning
G0	Rapid motion. Used to position the machine for non-milling moves.
G1	Line motion at a specified feed rate.
G2	Clockwise arc.
G3	Counterclockwise arc.
G4	Dwell.
G28	Return to machine home position.
G40	Cutter Diameter Compensation (CDC) off.
G41	Cutter Diameter Compensation (CDC) left.
G42	Cutter Diameter Compensation (CDC) right.
G43	Tool length offset (TLO).
G54	Fixture Offset #1.
G55	Fixture Offset #2.
G56	Fixture Offset #3.
G57	Fixture Offset #4.
G58	Fixture Offset #5.
G59	Fixture Offset #6.
G80	Cancel drill cycle.
G81	Simple drill cycle.
G82	Simple drill cycle with dwell.
G83	Peck drill cycle.
G84	Tap cycle.
G90	Absolute coordinate programming mode.
G91	Incremental coordinate programming mode.
G98	Drill cycle return to Initial point (R).
G99	Drill cycle return to Reference plane (last Z Height)

Table 1: Common G-Codes

1.6.10.M-Codes

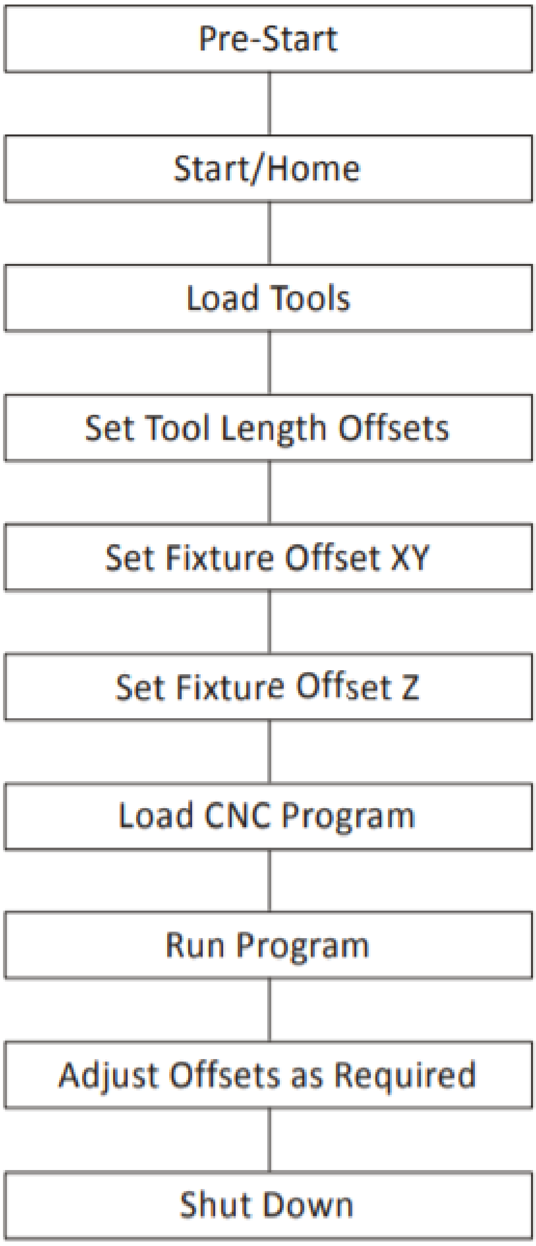
Codes that begin with M are called miscellaneous words. They control machine auxiliary options like coolant and spindle direction. Only one M-code can appear in each block of code. The table below lists the most common M codes and their meaning. A complete list of M-codes is included in Appendix B, G-M Code Reference.

Code	Meaning
M0	Program stop. Press Cycle Start button to continue.
M1	Optional stop. Only executed if Op Stop switch on the CNC control is turned ON.
M2	End of program.
M3	Spindle on Clockwise.
M4	Spindle on Counterclockwise.
M5	Spindle stop.
M6	Change tool.
M8	Coolant on.
M9	Coolant off.
M30	End program and press Cycle Start to run it again.

Table 2: Common M-Codes

1.6.11.Overview of CNC Setup and Operation

CNC machine setup and operation follows the process shown in Figure 1:



Pre-Start Before starting the machine, check to ensure oil and coolant levels are full. Check the machine maintenance manual if you are unsure about how to service it. Ensure the work area is clear of any loose tools or equipment. If the machine requires an air supply, ensure the compressor is on and pressure meets the machine requirements.

Start/Home Turn power on the machine and control. The main breaker is located at the back of the machine. The machine power button is located in the upper-left corner on the control face.

Load Tools Load tools into the tool carousel in the order listed in the CNC program tool list.

Set Tool Length Offsets For each tool used, jog the machine to find and then set the TLO.

Set Fixture Offset XY Once the vise or other fixture is properly installed and aligned on the machine, set the fixture offset to locate the part XY datum.

Set Fixture Offset Z Use a dial indicator and 1-2-3 block to find and set the fixture offset Z.

Load CNC Program Download the CNC program from your computer to the machine control using RS-232 communications, USB flash memory, or floppy disk.

Run Program Run the program, using extra caution until the program is proven to be error-free.

Adjust Offsets as Required Check the part features and adjust the CDC or TLO registers as needed to ensure the part is within design specifications.

Shut Down Remove tools from the spindle, clean the work area, and properly shut down the machine. Be sure to clean the work area and leave the machine and tools in the location and condition you found them.

1.7.Adjustable Cutting Parameters in Drilling

The three primary factors in any basic Drilling operation are speed, feed, other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right on the machine.

1.7.1.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 important 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. It is simply, 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.

1.7.2.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.

Fm= f x N (mm/min)

Here,

Fm is the feed in mm per minute,

f - Feed in mm/rev and

N - Spindle speed in r.p.m.

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.). 14 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 the 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 its elements.

1.8.1.Minitab Project and Worksheets

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spread sheet containing variables of data. Projects are made up of the 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 its 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.

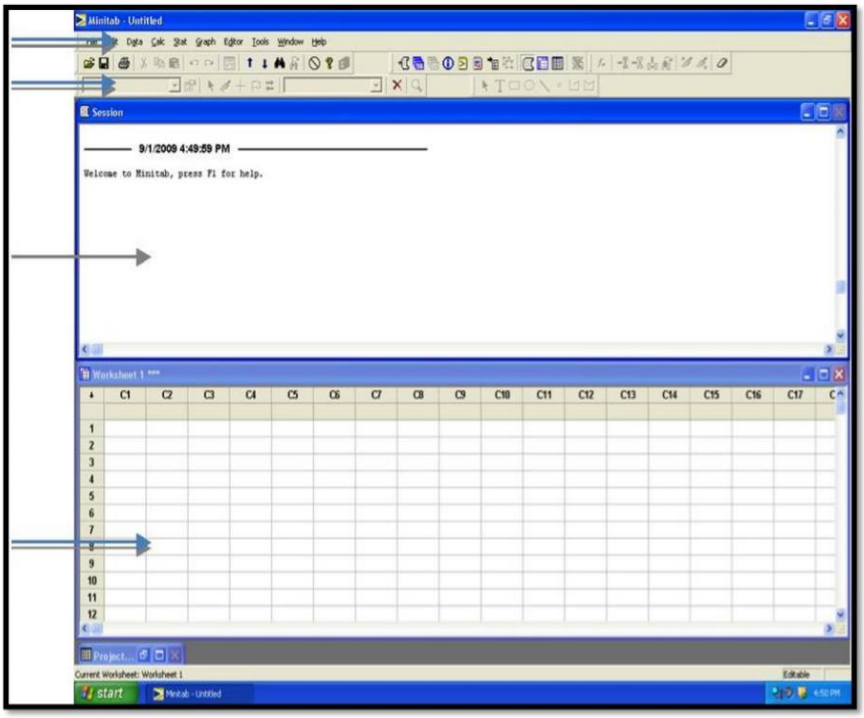
Two windows in MINITAB

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



1.9.Material Removal Rate (MRR)

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

1.10.Surface Roughness

The surface roughness is considered to be a measure of the technological quality of a product. Surface roughness is the one of the critical performance parameters that has an appreciable effect on several mechanical properties of machined parts such as fatigue behaviour, corrosion resistance, creep life, etc. It also affects other functional attributes of machined parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Hence, achieving the desired surface quality is of great importance for the functional behaviour of the mechanical parts. Out of all the surface condition criteria, Ra and Rt (expressed in μm) are often used to characterize the roughness of machined surfaces. Rt is total roughness (maximum depth or amplitude of the roughness), and Ra is arithmetic roughness (mean arithmetic deviation from the mean line of the roughness) as given:

$$Ra = \frac{\Sigma A + \Sigma B}{L}$$

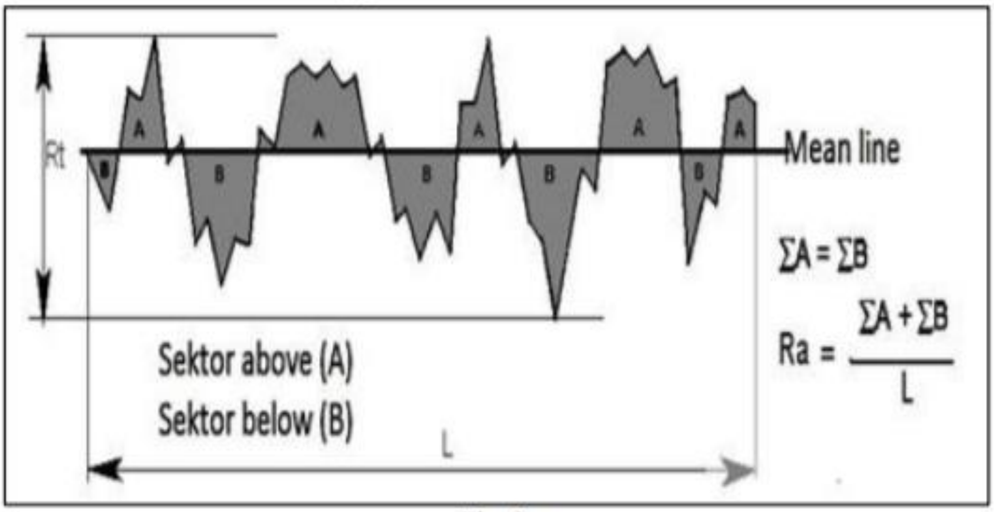


Fig. 2:

The manufacturing industries are focus on producing high quality products in time at minimum cost. The surface roughness is considered to be a measure of the technological quality of a product. Surface roughness is the one of the critical performance parameters that has an appreciable effect on several mechanical properties of machined parts such as fatigue behaviour, corrosion resistance, creep life, etc. It also affects other functional attributes of machined parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Hence, achieving the desired surface quality is of great importance for the functional behaviour of the mechanical parts.

CHAPTER-2

LITERATURE REVIEWS

Jaromír Audy [1], analyzed experimentally the effects of TiN, Ti(Al, N) and Ti(C, N) as well as a M35 HSS tool substrate material on the drill-life of the GP-twist drills by drilling the Bisalloy 360 steel work material. All these experiments have been statistically planned in order to establish the 'empirical' drill-life-cutting speed equations for each of the three coatings as well as to compare statistically the effects of these different coatings on the drill-life. The results demonstrated that although the coated drills performed very well at conditions much higher than applicable for the uncoated drills, none of the three coatings offered any statistically significant advantage over another coating in terms of the drill life.

Kadam and Pathak [2], analyzed experimental investigation was conducted to determine the effect of the input machining parameters cutting speed, feed rate, point angle and diameter of drill bit on Hass Tool Room Mill USA made CNC milling machine under dry condition. The change in chip load, torque and machining time are obtained through series of experiments according to central composite rotatable design to develop the equations of responses. The comparative performance of commercially available single layer Titanium Aluminum Nitride (TiAlN) and HSS tool for T105CR1 EN31 steel under dry condition is done. The paper also highlights the result of Analysis of Variance (ANOVA) to confirm the validity and correctness of the established mathematical models for in depth analysis of effect of finish drilling process parameters on the chip load, torque, and machining time.

AdemÇiçek et al., [3] have studied the effects of deep cryogenic treatment and drilling parameters on surface roughness and roundness error were investigated in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. In addition, optimal control factors for the hole quality were determined by using Taguchi technique. Two cutting tools, cutting speeds and feed rates were considered as control factors, and L8 orthogonal array was determined for experimental trials, for the input parameters.

Ulaş Çaydaş, [4] performed on HSS, K20 solid carbide, and TiN-coated HSS tools in dry drilling of AISI 304 austenitic stainless steel. The roles of spindle speed, feed rate, drill point angle, and number of holes on the surface roughness, tool flank wear, exit burr height, and enlargement of the hole size were experimentally investigated. The structure of this analysis has been determined by means of the technique called the design of experiments (DOE), which allows us to perform a relatively small number of experiments. An L9 orthogonal array was used to collect the experimental data. The experimental results demonstrated that the above-mentioned drilling performances showed a tendency to increase in response to the cutting parameters. TiN coated HSS drill showed the highest performance with longer tool life and higher hole quality, as well as lower surface roughness, followed by the K20 carbide and the HSS tools.

V Balakumaran, [5] investigated through the method and methodology of the Modified Taguchi optimization method for simultaneous minimization and maximization of Surface roughness (Ra), machining time and material removal rate of EN31 Alloy steel affect the aesthetical aspect of the final product and hence it is essential to select the best combination values of the CNC drilling process parameters to minimize as well as maximize the responses. The experiments were carried out by a CNC lathe, using physical vapor deposition coated Chromium nitride drilling tool bit for the machining of EN19. The experiments were carried out as per L9 orthogonal array with each experiment performed under different conditions of such as speed, type of drilling tool, and feed rate. The Taguchi method and analysis of variance (ANOVA) was employed by using MINITAB-15 software to identify the level of importance of the machining parameters on Surface roughness (Ra), Machining time and Material Removal Rate (MRR).

Nouari et al. [6] carried out experiments on Al2024 using uncoated carbide and coated carbide drills with different drill geometries. They concluded that low values of the surface roughness were obtained at high point angle and helix angle. The drill with the highest point angle of 180◦ also contributed well in minimizing the formation of burrs. In addition, minimum deviation from nominal drill size was obtained when there was a decrease in the web thickness and, increase in helix angle and point angle. Furthermore, it was reported that uncoated drills provided lower surface roughness compared to coated drills, where a possible explanation for this might be due to the low feed rate. However, diamond-coated drills were shown to be better at producing a minimum diameter deviation at high cutting velocity. Overall, their study concluded that coated drills did not contribute well to machining quality except for diamond and (TiAlN +WC/C) coated drills which were found to have results close to those of uncoated drills.

Kurt et al., [7] studies the impact of cutting speed, point angle, and coating materials on different characteristics of hole quality. The combination of point angle and selection of coated tool was: 118◦, TiN: 118◦, TiAlN: 118◦, Cobalt (Co) 5%:130◦, TiN: 130◦. The findings of their study suggested that the high cutting speed and feed rate contributed to the higher values of surface roughness and roundness of holes due to increases in drilling temperatures, vibrations and chatter. The point angle affected only hole size and did not contribute significantly to affect the surface roughness or hole roundness. The uncoated HSS with a point angle of 118◦ was considered better at low cutting parameters; however, the TiAlN and TiN coated HSS drills with a point angle of 118◦ were not suggested for drilling at low cutting parameters. Overall, the HSS-Co 5% with a point angle of 130◦ was found to out-perform in all cutting parameters. However, no reason was presented for the best performance of Co 5% HSS drills.

Reddy Sreenivasalu and **Dr.Ch. Srinivasa Rao**, [8] studied the effect of drilling parameters on surface roughness and roundness error were investigated in drilling of Al6061 alloy with HSS twist drill. Optimal control factors for hole quality were determined using Taguchi grey relational analysis. Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio were considered as the control factors. L18 orthogonal array was determined for experimental trials. Grey relational analysis was employed to minimize surface roughness and roundness error. The factors and their levels for the experiment are shown in Table 1. This work has indicated that the order of the importance of influential factors based on the Taguchi response in sequence is point angle, drill diameter, feed rate, %cutting fluid mixture ratio and cutting speed. Fig. 2 shows the relationship between average grey relational grade and experimental runs for the CNC drilling operations. It is evident that the grey relational grade fluctuates between 0.4 and 0.9.

Dinesh Kumar, **L.P. Singh**, **Gagandeep Singh**, [9] described the Taguchi technique for optimization of surface roughness in drilling process. In their investigation, Taguchi technique was used as one of the methods for minimizing the surface roughness in drilling mild steel. The Taguchi method is a powerful tool to design optimization for quality, was used to find optimal cutting parameters. The methodology is useful for modelling and analysing engineering problems. The purpose of this study is to investigate the influence of cutting parameters, such as cutting speed and feed rate, and point angle on surface roughness produced when drilling Mild steel. A plan of experiments, based on detailed L27 Taguchi design method, was performed drilling with cutting parameters in Mild steel. The orthogonal array, signal-to-noise ratio, and analysis of variance (ANOVA) were employed to investigate the optimal drilling parameters of Mild steel. From the analysis of means and ANOVA, the optimal combination levels and the significant drilling parameters on surface roughness were obtained. The optimization results showed that the combination of low cutting speed, low feed rate, and medium point angle is necessary to minimize surface roughness. The effect of parameters such as Cutting speed, feed rate and point angle and some of their interactions were evaluated using ANOVA analysis with the help of MINITAB 16 @ software. The purpose of the ANOVA was to identify the important parameters in prediction of Surface roughness.

Yogendra Tyagi, **Vedansh Chaturvedi**, et al. [10] studied the effect of cutting parameters such as spindle speed, feed rate and depth of cut for maximizing the material removal rate as well as minimizing the surface roughness in drilling mild steel. Taguchi L9 orthogonal array used in the experiment and the results were analyzed using Taguchi DOE software. They have found spindle speeds affects significantly surface roughness and feed rate largely affects material removal rate.

M Sundeep, **M Sudhahar**, et al. [11] have investigated the drilling of Austenitic stainless Steel (AISI 316) using Taguchi L9 array. Spindle speed, feed rate, and drill diameter were taken as process parameters. They found that spindle speed plays the most dominating role in the surface finish as well as Material removal rate in drilling.

Kadam Shirish, **M. G. Rathi** [12] focused on optimization of drilling parameters by using the Taguchi Method. Taguchi L9 orthogonal array was used to drill on EN-24 steel blocks. Uncoated M32 HSS twist drill has been used under dry condition. Cutting speed, feed rate and depth of hole were taken as the process parameter. They found that cutting speed has the most significant effect on surface roughness and the tool life.

Turgay Kıvak, **Gurcan Samtas**, et al. [13] studied the effect of cutting parameters such as cutting tool, cutting speed and feed rate on drilling of AISI 316 stainless steel. Experiments were conducted in CNC vertical machine using Taguchi L16 array. Coated and uncoated M35 HSS twist drill bit were employed under the dry condition for this purpose. Analysis of variance was employed to draw the effects of the control factors. They found that cutting tool and feed rate were the most significant factor on surface roughness and thrust force respectively.

Adem Çiçek, **Turgay Kıvak**, et al. [14] studied the effect of deep cryogenic and cutting parameters on surface roughness as well as roundness error in the drilling of AISI 316 austenitic stainless steel. Cutting tools, cutting speeds and feed rate were taken as the control factors. M35 twist drill bit was used in the experiment. Taguchi L8 orthogonal array was employed and multiple regression analysis was performed to find out the predictive equation of surface roughness.

A. Navanth, **T. Karthikeya Sharma** [15] concentrated on optimization of drilling parameters for obtaining minimum surface roughness and hole diameter by using Taguchi method. Al 2014 material and HSS twist drill bit have been selected for performing the experiment. Taguchi L18 orthogonal array was used and the results obtained were analyzed with the help of MINITAB 16. Analysis of variance (ANOVA) was employed to find out the optimal parameters from cutting tool, spindle speed and feed rate.

Reddy Sreenivasulu [16] concentrated on optimization of surface roughness in the drilling of Al 6061 using Taguchi design methodology and artificial neural network method. In their study cutting speed, feed rate, drill diameter, clearance angle and point angle were taken as process parameters and HSS twist drill bit as a tool. Taguchi L27 orthogonal array, S/N ratio, ANOVA were used to study the effects of the process parameters. They found that cutting speed, feed rate, drill diameter and point angle all were significant on surface roughness. The Optimal settings for roughness were found to be speed 800 rpm, feed rate .3 mm/rev, drill diameter 10 mm, clearance angle 40, point angle 1180.

J.Pradeep Kumar, P**.Packiaraj** [17] studied the effect of cutting parameters such as cutting speed, drill tool diameter feed and feed on the surface finish of OHNS material using HSS spiral drill bit as cutting tool. Taguchi L18 orthogonal array, S/N ratio, ANOVA and Regression analysis were employed to study the effect of process parameters on surface roughness. Experimental data were analysed using MINITAB 13 and they found that both speed and feed plays most important role in surface roughness, material removal rate.

B.Shivapragash, **K.Chandrasekaran**, et al. [18] focused on optimization of cutting parameters namely feed rate, spindle speed, depth of cut to study their influence in drilling composite Al-TiBr2. Taguchi methods with Grey Relational analysis were employed to optimize the factors. Taguchi L9 orthogonal array was used and optimal settings found for better surface finish were feed rate (1.5 mm/rev), spindle speed (1000 rpm) and depth of cut 6 mm.

Nalawade P.S. and **Shinde S.S.** [19] optimizes the process parameters speed, depth of cut, type of tool and feed to get better Surface Finish and Hole Accuracy in Drilling of EN-31 material. Taguchi L9 orthogonal array, Regression analysis, S/N ratio and ANOVA were employed to find out the optimal settings. Optimal settings for surface roughness were found to be Cutting speed (30 m /min), feed (.2 mm/min), type of tool (HSS uncoated).

Nisha Tamta, **R S Jadoun** [20] analyzed the effect of spindle speed, feed rate and drilling depth in drilling Aluminium alloy 6082. They used Taguchi L9 orthogonal array to perform the experiment. Analysis of variance (ANOVA), Signal to noise ratio (S/N) were employed to study the effects drilling parameters on surface roughness. For analyzing statistical software MINITAB-15 were used. They found that spindle speed 3000 rpm, feed rate 15 mm/min, drilling depth 9 mm were the optimum value. According to them, drilling depth was the most significant factor for surface roughness followed by spindle speed.

Srinivasa Reddy, **S. Suresh**, et al. [21] studied the impact of process parameters such as cutting speed, point angle and feed rate on surface roughness in the drilling of AL 6463 material. HSS drill bit was used as a tool and the experiment was performed in CNC drilling machine using Taguchi L9 orthogonal array. Analysis of variance (ANOVA), signal to noise ratio (S/N) were employed to find out the optimal drilling parameters. They found that Cutting speed, feed rate and point angle plays the most significant role on surface roughness during drilling of AL 6463 material.

Sathish Rao U And **Lewlyn .L.R. Rodrigues** [22] have made an attempt to investigate the effect of spindle speed, fibre orientation, feed rate and drill diameter on tool wear during dry drilling of GFRP components. HSS drill bit was used in the experiment. Taguchi L9 orthogonal array was used. S/N ratios, regression analysis, ANOVA were used to find out the optimal settings. They found that speed, feed rate, drill diameter has a significant effect on tool wear.

Arshad Noor Siddiquee, **Zahid A. Khan**, et al. [23] concentrated on optimising drilling parameters such as cutting fluid, speed, feed and hole depth in drilling AISI 312 material. All the experiments were done in CNC lathe machine using solid carbide cutting tool. Taguchi L18 orthogonal array was used for the experiment. Signal to noise ratio (S/N), analysis of variance (ANOVA) were employed to find out the effects of cutting parameters on surface roughness. They found that in the presence of cutting fluid, speed 500 rpm, feed .04 mm/sec, hole depth 25 mm were the optimum value of process parameters. It is seen from the ANOVA analysis that speed was the most significant factor followed by cutting fluid, feed and hole depth for surface roughness.

Vishwajeet N. Rane, **Ajinkya P.Edlabadkar**, et al. [24] concentrated on optimizing drilling parameters such as cutting speed, feed and point angle for resharpened HSS twist drill bit on hardened boron steel using Taguchi method. Taguchi L16 orthogonal array was used to perform the experiment in a double spindle drilling machine. Analysis of variance was employed to find out effects of process parameters on surface roughness. They found that point angle was the most significant factor for tool wear and feed rate for surface roughness.

CHAPTER-3

DESIGN OF EXPERIMENTS

3.1.Design of Experiments (DOE) Overview

In industry, designed experiments can be used to 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 very important 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 effects that are important. If there is an interaction between two input variables

They should be included in design rather than doing 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 analyze your measurement system.

3.1.2.Screening

In many process 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 really important 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 useful in some screening experimentation and robustness testing.
- General full factorial designs (designs with more than two-levels) may also be useful for small screening experiments.

3.1.3.Optimization

After identifying the vital variables by screening, there is 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 methods for designing and analyzing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a special class of response surface designs where the proportions of the components (factors), rather than their magnitude, are important.
- 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 analyzing 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.

3.1.5.Advantages and 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 important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Besides from that, the mathematical model generated can be used as a prediction model which can 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 function in such manner 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 error occurring. Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behaviour. However, when it comes to nonlinear behaviour, DOE does not always give the best results.

3.1.6.Hierarchy

You can determine how Minitab enforces model hierarchy during a stepwise procedure. The Hierarchy button is disabled if you specify a non-hierarchical model in the Model dialog box.

For example, a model that includes the interaction term A*B*C is hierarchical if it includes these terms: A, B, C, A*B, A*C, and B*C.

Models can be non-hierarchical. Generally, you can remove lower order terms if they are insignificant, unless subject area knowledge suggests that you include them. Models that contain too many terms can be relatively imprecise and can reduce the ability to predict the values of new observations.

Consider the following tips:

1. Fit a hierarchical model first. You can remove insignificant terms later.
2. If you standardize your continuous predictors, fit a hierarchical model to produce an equation in uncoded (or natural) units.
3. If your model contains categorical variables, the results are easier to interpret if the categorical terms, at least, are hierarchical.

3.2.Response Surface Methodology

Response surface methodology is a collection of mathematical and statistical techniques, which are useful for the modelling and analysing the engineering problems and developing, improving, and optimizing processes. It also has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs, and it is an effective tool for constructing optimization models. RSM consists of the experimental strategy for exploring the space of the process or input factors, empirical statistical modelling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the levels or values of the process variables that produce desirable values of the response outputs. Response surface method designs also help in quantifying the relationships between one or more measured responses and the vital input factors. The first step of RSM is to define the limits of the experimental domain to be explored. These limits are made as wide as possible to obtain a clear response from the model. The cutting speed, feed rate, and cutting environment are the drilling variable, selected for our investigation. In the next step, the planning to accomplish the experiments by means of RSM using a Box-Behnken design. In many engineering fields, there is a relationship between an output variable of interest (y) and a set off controllable variables (x1, x2,…xn). The relationship between the drilling control parameters and the responses is given as:

$$y = f(x_1, x_2, \ldots, x_n) + \varepsilon$$

where, ε represents the noise or error observed in the response (y). If we denote the expected response be $E(y) = f(x_1, x_2, \ldots x_n) = \eta$ and then the surface represented by;

$$\eta = f(x_1, x_2, \ldots x_n)$$

is called a response surface. The variable x1, x2,…xn in Eq. 2 are called natural variables, because they are expressed in natural units of measurement. In most RSM problems, the form of the relationship between the independent variables and the response is unknown, it is approximated. Thus, the first step in RSM is to find an appropriate approximation for the true functional relationship between response and the set of independent variables. Usually, a low-order polynomial in some region of the independent variables is employed. If the response is well modelled by a linear function of the independent variables, then the approximating function is the first order model;

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon$$

If there is curvature in the system, then a polynomial of higher degree must be used, such as the second order model;

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \sum_{i}^{k-1} \sum_{j}^{k} \beta_{ij} x_i x_j + \varepsilon$$

where, $i = 1, 2, \ldots, k-1$ and $j=1,2,\ldots,k$ also $i<j$

3.3.Taguchi Method

Taguchi Method has been developed by a Japanese engineer Dr Genichi Taguchi. It is a statistical tool for standardize the fractional factorial design. He designed orthogonal array (OA) to standardize it and to optimize the levels of process parameters. Taguchi believed in offline quality control. To produce robust design, which are less sensitive to the uncontrollable environmental factors, is the main aim of the Taguchi Method. Taguchi developed the concept of Taguchi loss function and signal to noise (S/N) ratio. S/N ratio is divided into Three groups namely:

1. Smaller the better,
2. Larger the better,
3. Nominal the best type.

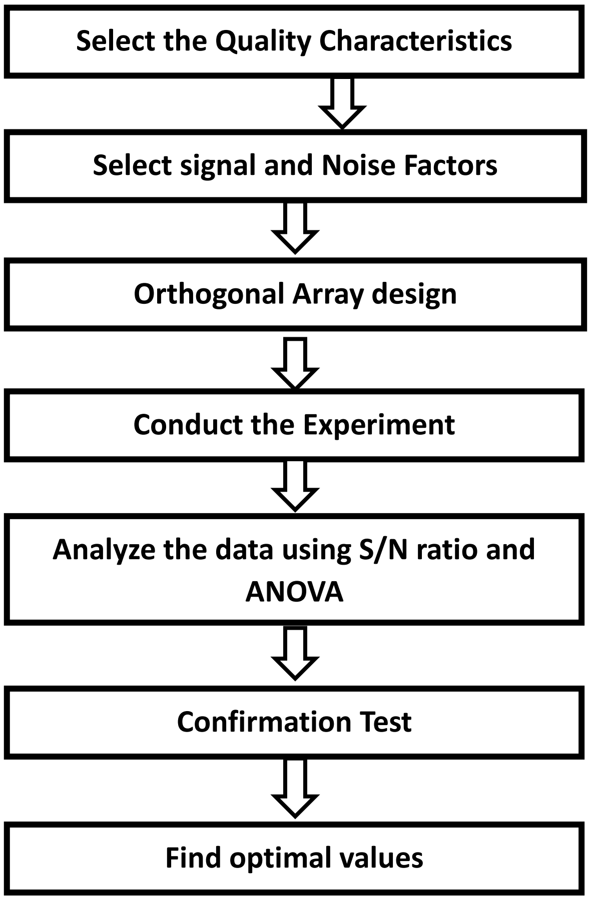


Figure.7 Taguchi Method

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his approach, using experimental design for: – designing products/processes so as to be robust to environmental conditions – designing and developing products/processes so as to be robust to component variation; – minimizing variation around a target value. The philosophy of Taguchi is broadly applicable. He proposed that engineering optimization of a process or product should be carried out in a three-step approach, i.e., system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost. The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. Basically, classical parameter design, developed by Fisher, is complex and not easy to use. Especially, a large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio g. Usually, there are three categories of the performance characteristic in the analysis of the S/N ratio, that is, the lower-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio g. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. In this paper, the cutting parameter design by the Taguchi method is adopted to obtain optimal machining performance in turning.

$$\text{Nominal is the best: } S/N_T = 10\log\left(\frac{\bar{y}}{s_y^2}\right) \quad (1)$$

$$\text{Larger-is-the better(maximize): } S/N_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

$$\text{Smaller-is-the better(minimize): } S/N_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right) \quad (3)$$

where y, is the average of observed data, s2 y is the variance of y, n is the number of observations and y is the observed data. Notice that these S/N ratios are expressed on a decibel scale. We would use S/NT if the objective is to reduce variability around a specific target, S/NL if the system is optimized when the response is as large as possible, and S/NS if the system is optimized when the response is as small as possible. Factor levels that maximize the appropriate S/N ratio are optimal. The goal of this research was to produce minimum surface roughness (Ra) in a turning operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study. The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated. Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Calculate the total loss function and the S/N ratio.
- Analyse the experimental results using the S/N ratio and ANOVA.
- Select the optimal levels of process parameters.
- Verify the optimal process parameters through the confirmation experiment.

3.4.Analysis of Variance (ANOVA) Using MINITAB

ANOVA was developed by the English statistician, R.A. Fisher (1890-1962). Though initially dealing with agricultural data, this methodology has been applied to a vast array of other fields for data analysis. Despite its widespread use, some practitioners fail to recognize the need to check the validity of several key assumptions before applying an ANOVA to their data. It is the hope that this article may provide certain useful guidelines for performing basic analysis using such a software package.

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups), in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error. For this reason, ANOVAs are useful in comparing (testing) three, or more means (groups or variables) for statistical significance.

ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result (when a probability (p-value) is less than a threshold (significance level)) justifies the rejection of the null hypothesis. The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error. ANOVA is the synthesis of several ideas and it is used for multiple purposes. As a consequence, it is difficult to define concisely or precisely.

3.4.1.Characteristics of ANOVA

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations. In the era of mechanical calculation, it was common to subtract a constant from all observations (when equivalent to dropping leading digits) to simplify data entry. This is an example of data coding.

Classical ANOVA for balanced data does three things at once:

1. As exploratory data analysis, an ANOVA is an organization of additive data decomposition, and its sums of squares indicate the variance of each component of the decomposition (or, equivalently, each set of terms of a linear model).
2. Comparisons of mean squares, along with F-tests ... allow testing of a nested sequence of models.
3. Closely related to the ANOVA is a linear model fit with coefficient estimates and standard errors.

In short, ANOVA is a statistical tool used in several ways to develop and confirm an explanation for the observed data.

Additionally:

It is computationally elegant and relatively robust against violations to its assumptions.

4. ANOVA provides industrial strength (multiple sample comparison) statistically.
5. It has been adapted to the analysis of variety of experimental designs.

CHAPTER-4

EXPERIMENTAL DETAILS

This chapter presents the details of work piece (chemical and mechanical properties), drill bits, CNC drilling machine specifications, cutting process parameters and their levels, orthogonal array (L18) design and the setup conditions in measurement of surface roughness values for the machined components etc.

4.1.Work Material and Drills

In the present work the drills are made on a plate of carbon alloy C45 having 30mm thickness using HSS twisted drills (10mm) shown in the figure 4.2. C45 grade steel is defined as medium carbon steel offering tensile strength in the modest range. the material can be maneuverer with hardening by means of quenching and tempering on focused and restricted areas. This material is typically used for

- Screws
- Shafts
- Forgings
- Wheel Tire
- Sickles
- Axes
- Knives
- Wood Working drills
- Hammers

Fig. C45 Carbon steel

Fig. HSS TWIST DRILL BITS

Fig. HSS COBALT TWIST DRILL BITS

4.2.Chemical Composition and Mechanical Properties of c45 Carbon steel

C45 carbon steel alloy is an alloy in the carbon-silicon-manganese-sulphur-chromium-pottasium-molybdenium-nickel-phosphorous family. It has the Tensile strength of 565 MPa and Tensile strength yield of 310 MPa. The chemical composition and mechanical properties of C45 Carbon steel are given in the tables

Table. Chemical composition of C45 Material

Carbon(C)	0.42 to 0.5% max
Chromium (Cr)	0.2 to 0.4%
Potassium(K)	0.0 to 0.1%
Sulphur(S)	0.0 to 0.045%
Molybdenum (Mo)	0.0 to 0.1%
Manganese (Mn)	0.50 to 0.80%
Silicon (Si)	0.0 to 0.4%
Phosphorous(P)	0.03%
Nickel (Ni)	0.0 to 0.4%

Table. Mechanical Properties of C45 material

Density	7.7 - 8.03 gm/cm3
Ultimate Tensile Strength	565 MPa
Yield Strength	310 MPa
Hardness	84 BHN
Elongation	16.0%
Youngs modulus	190 GPa
Resistivity	0.7
Reduction of Area	40.0%
Thermal conductivity	40 - 45.0 w/m-k

4.3.CNC Machine Specifications used for Drilling

In the present work the experiments were conducted on CNC drilling machine and the specifications of the machine were tabulated in table

Table. CNC Machine Specification

Manufacturer	Kitamura
Model	Mycentre 2/585
Type	Vertical Machining Centre with 4 axis
Auto Tool Changer	24 position
X-Axis	585mm
Y-Axis	430mm
Z-Axis	460mm

Fig. CNC Machine

4.4.Selection of Process Variables

A total of three process variables are selected for the experimental procedure.

The deciding process variables are

1. Tool Type
2. Point Angle
3. Speed
4. Feed

- 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.

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. Process Parameters and Their Levels

Parameter	**Level1**	**Level2**	**Level3**
Tool Type	HSS	HSS-Cobalt	
Point angle	90	118	136
Speed	750	600	480
Feed	0.03	0.06	0.09

L18 Orthogonal Array:

Tool Type	**Angle**	**Speed**	**Feed**
HSS	90	750	0.03
HSS	90	600	0.06
HSS	90	480	0.09
HSS	118	750	0.03
HSS	118	600	0.06
HSS	118	480	0.09
HSS	136	750	0.06
HSS	136	600	0.09

HSS	136	480	0.03
HSS_COBALT	90	750	0.09
HSS_COBALT	90	600	0.03
HSS_COBALT	90	480	0.06
HSS_COBALT	118	750	0.06
HSS_COBALT	118	600	0.09
HSS_COBALT	118	480	0.03
HSS_COBALT	136	750	0.09
HSS_COBALT	136	600	0.03
HSS_COBALT	136	480	0.06

4.5.CNC Machine Program

```
%
O0000
G21
G0G17G40G49G80G90
G0G90G54
G0G90X-15.Y30.
S1000M3
G43H1Z50.M8
Z1.
G1Z-3.F80.
G0Z50.
X15.
Z1.
G1Z-3.
G0Z50.
X-15.
Z1.
G1Z-3.
G0Z50.
X-30.
Z1.
G1Z-3.
```

```
G0Z50.
X-15.Y0.
Z1.
G1Z-3.
G0Z50.
X15.Y.740.
Z1.
G1Z-3.
G0Z50.
X30.
Z1.
G1Z-3.
G0Z50.
X15.Y-30.
Z1.
G1Z-3.
G0Z50.
Y-30.
G1Z-3.
G0Z50.
X-30.Y-15.
Z1.
G1Z-3.
G0Z50.
X-29.853Y-0.591
Z1.
G1Z-3.
G0Z50.
X30.149Y.296.
Z1.
G1Z-3.
G0Z50.
X15.666Y-44.041
Z1.
G1Z-3.
G0Z50.
```

X-15.37Y43.45

Z1.

G1Z-3.

G0Z50.

M5

G91G28Z0.M9

G28Y0.

M30

%

Fig. Drilling Operation

Fig. Surface Roughness Tester (Profilometer)

CHAPTER-5

RESULTS AND DISCUSSIONS

The experimental results and the optimization of those using Taguchi Method and Response Surface Methodology were explained in this chapter. The results of Material Removal Rate and Surface Roughness measured were depicted in table …The observed results were analysed using MINITAB-17 software.

Table. Experimental Results

S.No	Tool Type	PA	S	f	MRR	Ra
1	HSS	90	750	0.03	0.047	2.887
2	HSS	90	600	0.06	0.091	3.687
3	HSS	90	480	0.09	0.133	4.777
4	HSS	118	750	0.03	0.187	2.632
5	HSS	118	600	0.06	0.234	3.045
6	HSS	118	480	0.09	0.234	3.736
7	HSS	136	750	0.06	0.461	3.086
8	HSS	136	600	0.09	0.592	3.379
9	HSS	136	480	0.03	0.64	4.179
10	HSS-COBALT	90	750	0.09	0.573	3.208
11	HSS-COBALT	90	600	0.03	0.611	4.005
12	HSS-COBALT	90	480	0.06	0.993	4.679
13	HSS-COBALT	118	750	0.06	0.745	2.833
14	HSS-COBALT	118	600	0.09	0.778	3.125
15	HSS-COBALT	118	480	0.03	0.808	3.344
16	HSS-COBALT	136	750	0.09	0.903	2.89
17	HSS-COBALT	136	600	0.03	0.914	3.465
18	HSS-COBALT	136	480	0.06	0.927	3.603

5.1.Taguchi Analysis

Taguchi results of MRR and Ra were discusses here, response tables for MRR and Ra were given in table….and ….. respectively. Based on signal-to-noise ratio values, the main effect plots for both the responses were drawn and shown in figures ..and …. Respectively. From the plots, the optimal combinations of process parameters for the responses were found.

MRR versus Tool Type, PA, S, f

Table. Response Table for Signal to Noise Ratios of MRR

S.No	Level	Tool Type	PA	s	f
1	1	-13.319	-12.349	-6.098	-8.658
2	2	-2.01	-7.731	-7.535	-7.236
3	3		-2.914	-9.361	-7.099
4	Delta	11.309	9.436	3.263	1.558
5	Rank	1	2	3	4

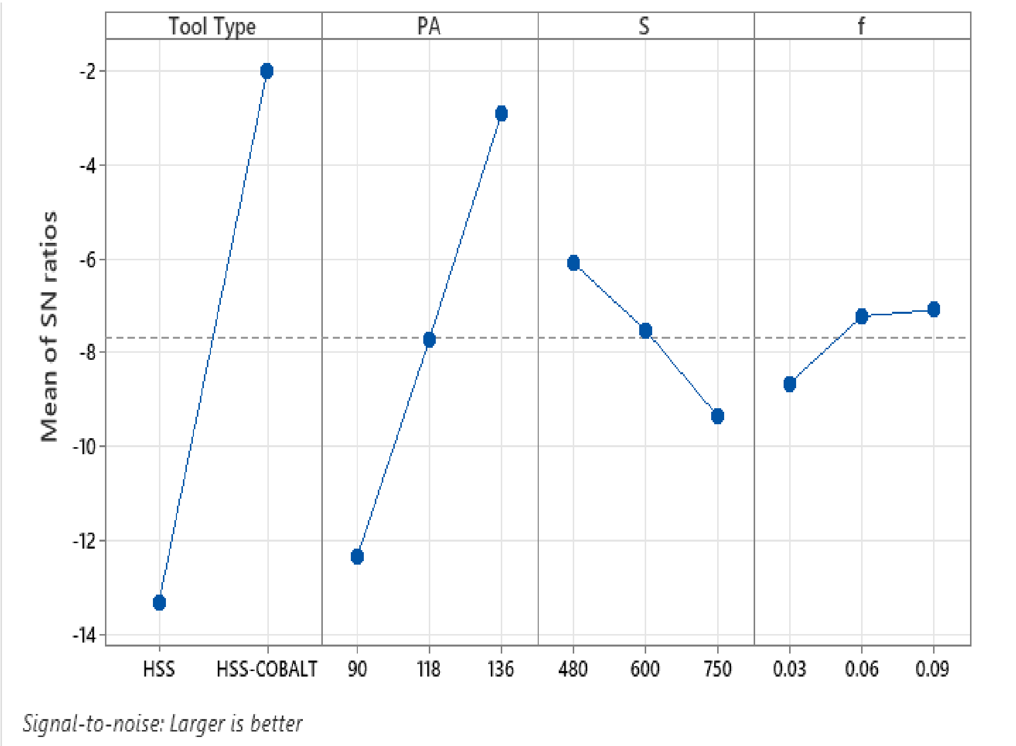


Figure.15 Main Effects Plot for SN Ratio For MRR

Ra versus Tool Type, PA, S, f

Table. Response Table for Signal to Noise Ratios

S.No	Level	Tool Type	PA	s	f
1	1	-10.715	-11.618	-12.079	-10.561
2	2	-10.684	-9.825	-10.721	-10.729
3	3		-10.655	-9.298	-10.808
4	Delta	0.032	1.792	2.781	0.247
5	Rank	4	3	1	2

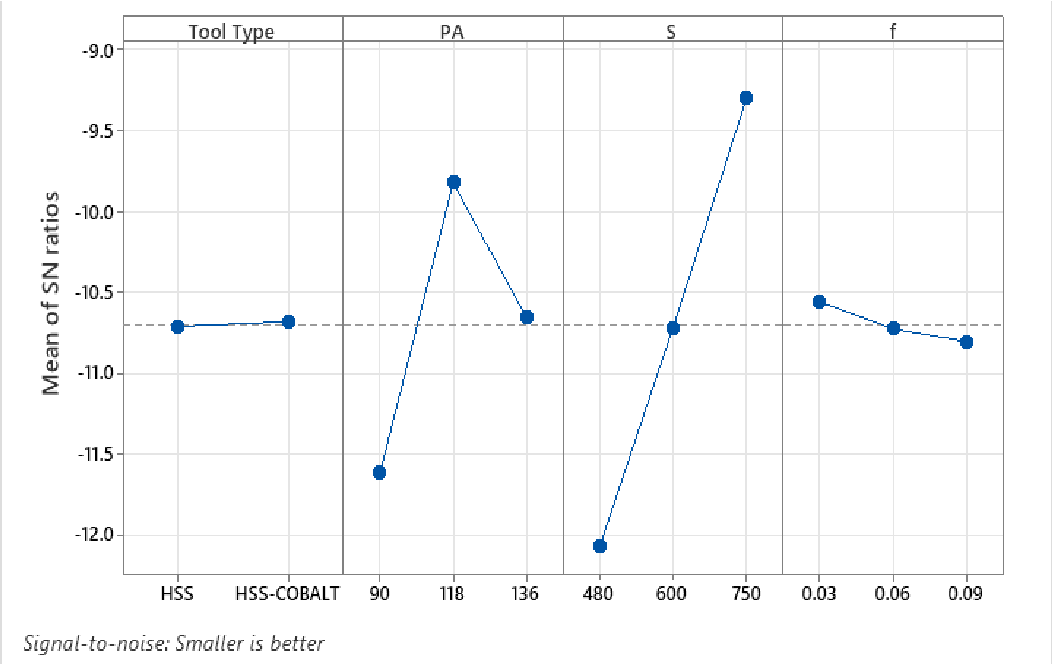


Figure. Main Effects Plot For SN Ratio for Ra

5.2.Response Surface Methodology

RSM was used to analyze the effect of process parameters on the responses. The results obtained in MINITAB for MRR and Ra were depicted in table ….and……. The pareto charts shown in figures ….and…. showing that the parameters effect and interaction effects of between the parameters over the responses. From the results it is found that tool type and speed are the main effecting parameters for the responses respectively. The residual analysis has been done and from the plots ……and ……it is found that the errors are following the normality and constant variance and hence the models prepared for the responses were best fit and they can be use for the prediction of responses.

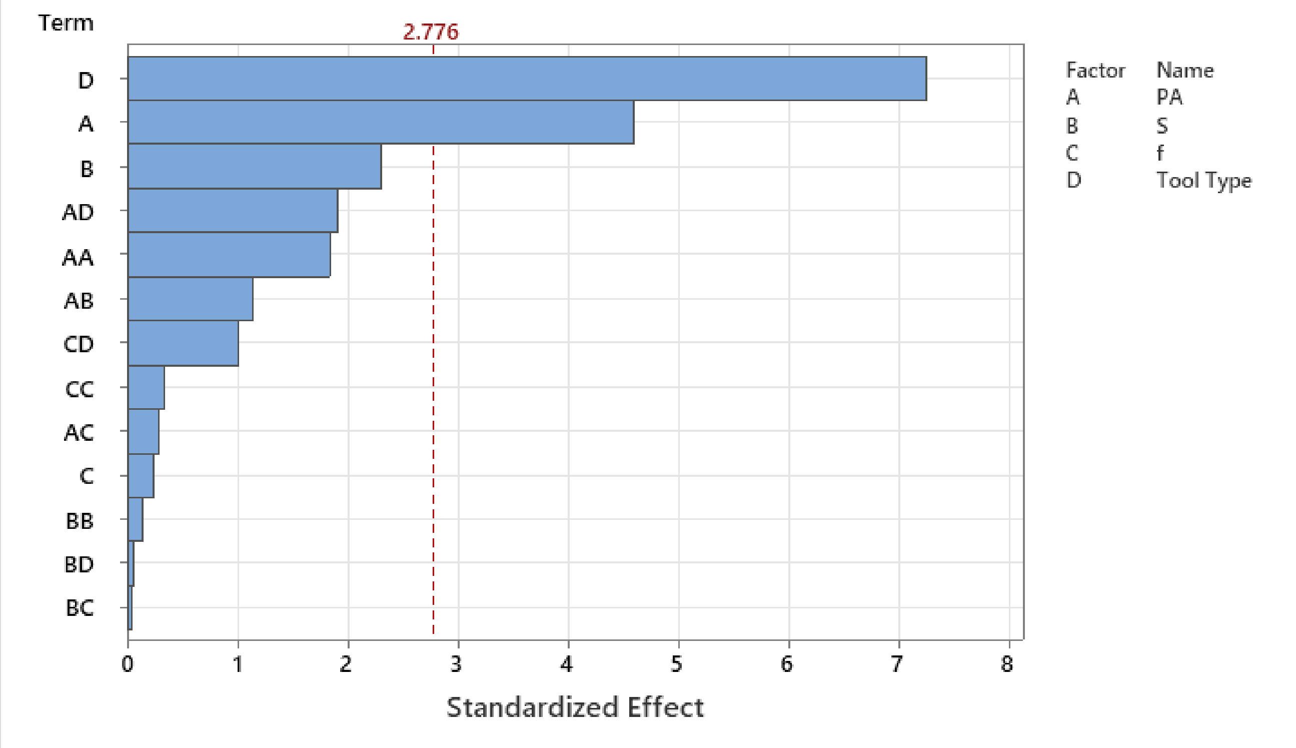


Figure. Pareto Chart For MRR

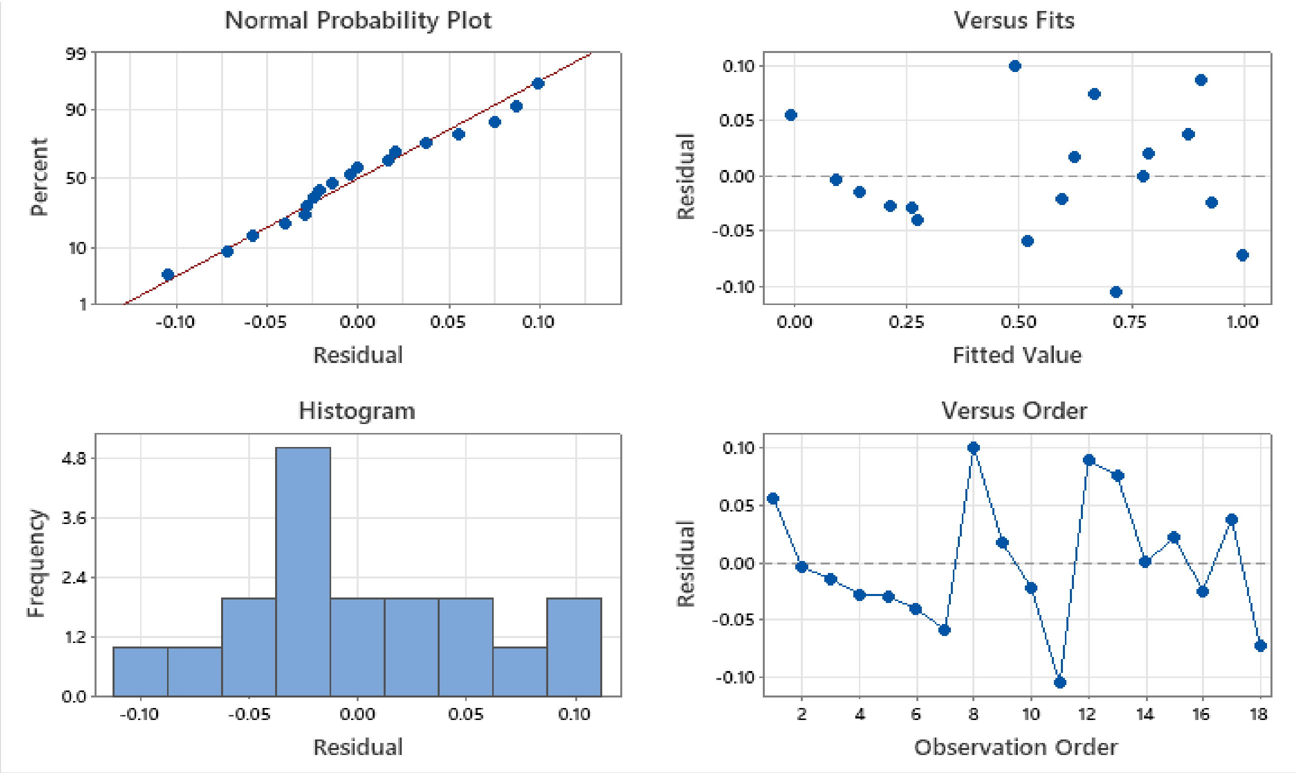


Figure. Residual Plots For MRR

Response Surface Regression: Ra versus PA, S, f, Tool Type

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	13	6.39732	0.4921	94.97	0
Linear	4	2.98327	0.74582	143.93	0
PA	1	0.26128	0.26128	50.42	0.002
S	1	2.52721	2.52721	487.72	0
f	1	0.06867	0.06867	13.25	0.022
Tool Type	1	0.05194	0.05194	10.02	0.034
Square	3	1.07361	0.35787	69.06	0.001
PA*PA	1	1.05729	1.05729	204.04	0
S*S	1	0.00749	0.00749	1.45	0.296
f*f	1	0.0021	0.0021	0.41	0.559
2-Way Interaction	6	0.79905	0.13317	25.7	0.004
PA*S	1	0.34436	0.34436	66.46	0.001
PA*f	1	0.03926	0.03926	7.58	0.051
PA*Tool Type	1	0.21635	0.21635	41.75	0.003
S*f	1	0.12435	0.12435	24	0.008

S*Tool Type	1	0.20668	0.20668	39.89	0.003
f*Tool Type	1	0.02144	0.02144	4.14	0.112
Error	4	0.02073	0.00518		
Total	17	6.41805			

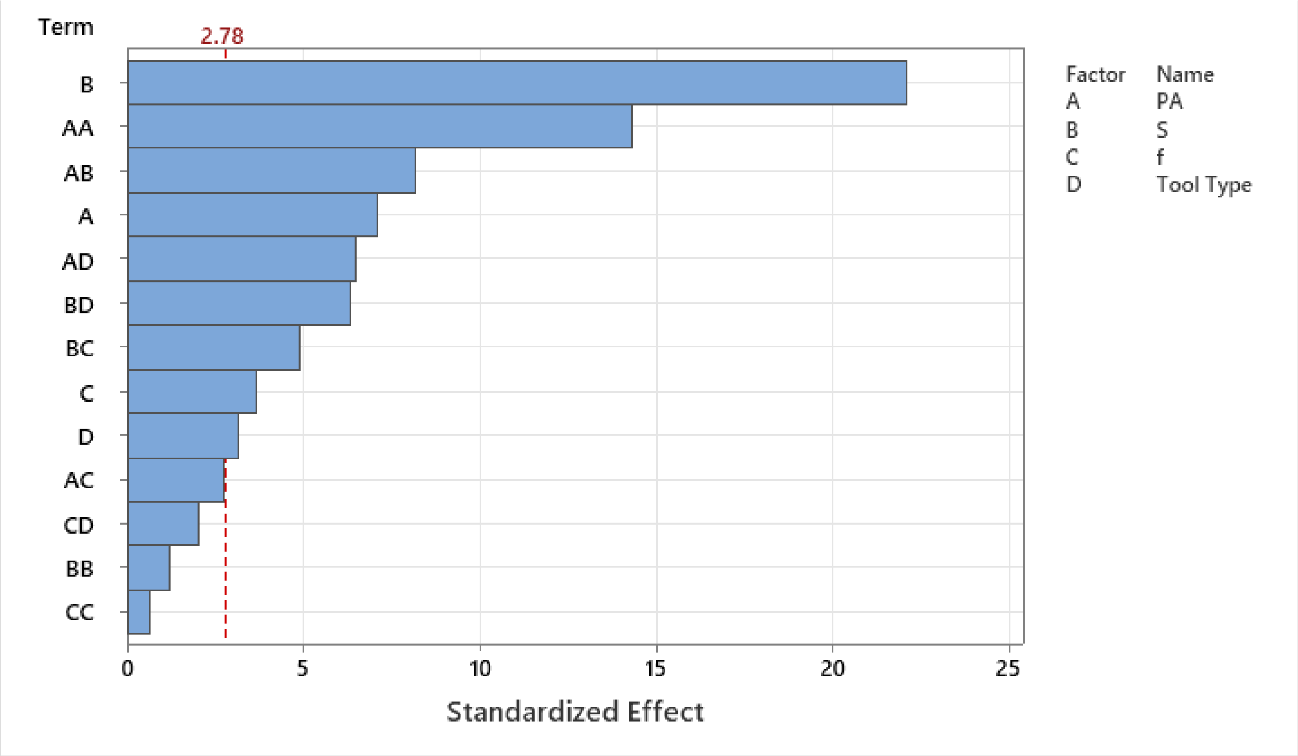


Figure. Pareto Chart for Ra

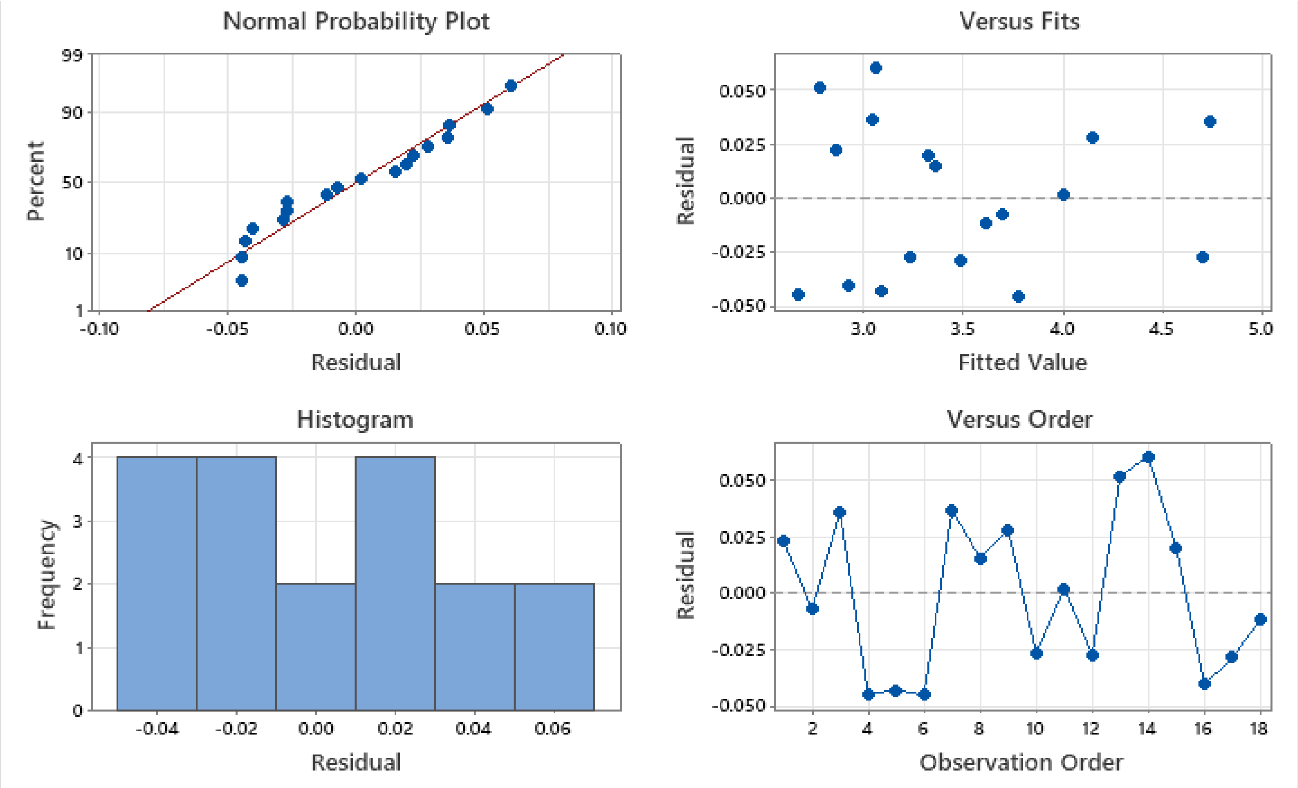


Figure. Residual Charts for Ra

CHAPTER-6

CONCLUSIONS

1) The Signal-to-Noise ratios results showed that, tool type and speed are the main effecting factors for the material removal rate and surface roughness respectively.
2) From the Main Effect Plots results,
   i.) The Optimal Combination of Process Parameters for MRR is obtained at
   Tool type: level 2, HSS-Cobalt.
   Point Angle: level3, 136degree
   Speed: level1, 400Rpm
   Feed: level3, 0.09mm/rev.
   ii.) The optimal combination of process parameters for Surface Finish are found as:
   Tool Type: Level-2, HSS-Cobalt
   Point angle: Level-2 ,118degree
   Speed: Level-3 ,750Rpm
   Feed: Level-1 ,0.03mm/Rev
3) The RSM and Pareto chart results found that the tool type and speed are the most influencing factors for the responses respectively.

CHAPTER-7

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