A DISSERTATION

Report On

"Experimental Investigation of Turning Process Parameters of Nimonic-80 Using Taguchi's Design Of Experiment"

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ABSTRACT

Metal cutting process is the most complex process which has many factors contributing towards the quality of the finished product. Turning is one among the metal cutting process in which quality of the finished product depends mainly upon the machining parameters such as speed, depth of cut, feed rate, type of coolant used, types of inserts used etc. Similarly the work piece material plays a vital role in metal cutting process. In turning process achieving a good surface quality and minimum cutting forces are the most importance. It involves many process parameters which directly or indirectly influence the surface roughness and cutting forces of the product in common. A precise knowledge of these optimum parameters would facilitate to reduce the machining costs and improve product quality. In this project turning of Nickel alloy as a work piece and carbide insert tool is performed. The cutting parameters are optimized by using Taguchi method. The range of parameters are cutting speed(100,125,150 m/min) ,feed rate(0.1,0.2,0.3 mm/rev), depth of cut(0.4,0.8,1.2 mm) and the different tool geometries with the use of Taguchi design of experiment to optimize and analyze the multi response parameters surface roughness and cutting forces.

Key words: Turning, Nimonic-80, Surface Roughness, Cutting Forces, Taguchi.

Chapter 1: INTRODUCTION

Turning is the most basic machining processes. The part is rotated while a single point cutting tool is moved parallel to the axis of rotation. Turning can be done on the external surface of the part as well as internally (boring). The starting material is generally a work piece generated by other processes such as casting, forging, extrusion, or drawing. Turning can be done in two ways whether manually, in a traditional form of lathe, which usually requires continuous supervision by the operator, or by using a Computer-controlled and automated lathe which does not requires continuous supervision. This type of machine tool is referred to as having computer numerical control, better known as CNC and is commonly used with many other types of machine tools besides the lathe. The turning process can be of different types such as straight turning, taper turning, profiling or external grooving. Turning process used to produce different types of shapes of materials such as straight, conical, curved, or grooved work pieces. In general, turning uses single-point cutting tools. Each group of work piece materials has a minimum set of tools angles which have been developed through the years. In turning process, parameters such as cutting tool geometry and materials, number of passes, depth of cut for each pass, the depth of cut, feed rates, cutting speeds as well as the use of cutting fluids will affect the production costs, MRRs, tool lives, cutting forces, and the machining qualities like the surface roughness, the roundness of circular and dimensional deviations of the product.

1.1 Machining parameters in turning process

In the process of metal cutting, there are many factors who relate the process planning for machining operations. These factors can be classified as follows: i. Type of machining operations (turning, facing, milling, etc.), ii. Parameters of machine tools (rigidity, horse power, etc.), iii. Parameters of cutting tools (material, geometry, etc.), iv. Parameters of cutting conditions (cutting speed, feed rate, depth of cut, etc.), v. Characteristics of work pieces (material, geometry, etc.).

a) Process Parameters

- **Cutting speed** - The cutting speed of a tool is the speed at which the metal is removed by the tool from the work material.

  In a lathe it is the peripheral speed of the work part in m/min.

  V = лDN/1000 (m/min)

Where D, N are diameter of work piece (mm) and cutting speed (rpm) respectively.

- **Depth of cut (*d*):** The depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of the work piece in mm.
- **Spindle speed** - The rotational speed of the spindle and the work piece in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the work piece where the cut is being made
- **Feed rate** – It is the speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in inches per minute (IPM) and is the product of the cutting feed (IPR) and the spindle speed (RPM).

b) Response Parameters

- **Material removal rate:** This is a production term usually measured in cubic inches per minute. Increasing this rate will resulting get a part done quicker and therefore probably for less money, but increasing the material removal rate is often increases in tool wear, poor surface finishes, poor tolerances, and other problems. Optimizing the machining process is a very difficult problem.
- **Tool wear rate**: The rate at which the cutting edge of a tool wears away during machining. It is usually measured in cubic inches per minute. As the rate will increases the production rate will automatically goes down. It will result in the wear of the tool.
- **Surface Finish**: The degree of smoothness of a part's surface after it has been manufactured. Surface finish is the result of the surface roughness, waviness, and flaws remaining on the part.

  Surface roughness plays a vital role as it affects the fatigue strength, wear rate, coefficient of friction, and corrosion resistance of the machined components. In actual practice, there are various factors which can affect the surface roughness, i.e., tool variables, workpiece hardness and cutting conditions. Tool variables include with the tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool point angle, etc. Theoretical surface roughness achievable based on tool geometry and feed rate is given approximately by the formula: $Ra = 0.032\ f\ 2/r\varepsilon$.
- **Cutting Forces:** Cutting forces are necessary for evaluation of power consumption during machining. Cutting forces also used for design of machine tool components

and the tool body. Cutting forces affects the deformation of the work piece machined, its dimensional accuracy, machine stability and chip formation.

It is important to predict quantity of cutting force and how different cutting parameters are affecting cutting force even before setting up the machining operation due to following reasons.

1. In order to design of mechanical structure of cutting machine which will withstand cutting force and thrust force effectively.
2. To determine power consumption during machining process. This will help in selecting motor drive.
3. To predict tool life and to increase productivity.

The cutting force is characterized as single in case of turning but that force is resolved into three components for ease of analysis and exploitation. Fig 1.1 visualizes how the single cutting force in turning is resolved in three components along the three orthogonal directions; X, Y and Z.

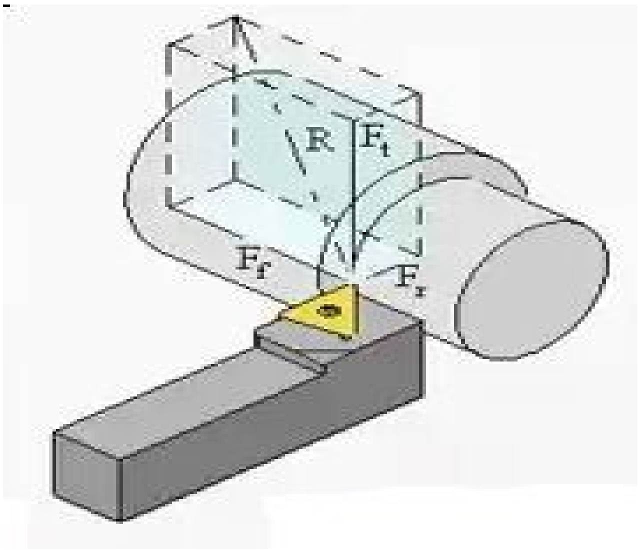


Fig. 1.1: Cutting Forces acting on workpiece [31]

The figure 1.1 gives details about the cutting forces. In figure the Radial force (Fr), Feed force (Ff) and Tangential force (Ft) are given. Radial force is always act along radius. Feed force acts along the parallel to the axis and Tangential force acts along perpendicular to the axis of workpiece.

Px = It is nothing but the feed force. Axial component taken in the direction of longitudinal feed or X axis. It is important component but least harmful and less significant.

PY = It is Radial or transverse component taken along Y axis. It may not be that large in magnitude but is responsible for causing dimensional inaccuracy and vibration.

Pz = Tangential component taken in the direction of Z axis. It is the main or major component as it is the largest in magnitude. It is also called as power component as it being acting along multiplied by PX & PY.

Chapter 2: LITERATURE REVIEW

Konig[1] have reported that CBN and ceramic cutting tools are widely used in industries for the machining of the various hard materials. Cutting tool geometry plays a vital role in hard turning process. The rake angle and the nose radius of the turning inserts directly affect the cutting forces, power and surface finish. The edge strength of the cutting inserts depends upon edge preparation, i.e. by the honing radius, chamfer angles. Some investigations related to the effect of tool geometry have been reported by the researchers.

Drawish[5] studied the effect of the tools and cutting parameters on surface roughness of 718 nickel alloy. This work also showed that feed rate has the dominant effect on surface roughness amongst the parameters studied, irrespective of tool materials used.

Sahin & Motorcu[9] Surface roughness plays an important role as it influences the fatigue strength, wear rate, coefficient of friction, and corrosion resistance of the machined components. In actual practice, there are many factors which affect the surface roughness, i.e., tool variables, workpiece hardness and cutting conditions. Tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool point angle, etc. Theoretical surface roughness achievable based on tool geometry and feed rate is given approximately by the formula: $Ra = 0.032\ f\ 2/r\varepsilon$. In hard turning, surface finish has been found to be influenced by a number of factors such as feed rate, cutting speed, tool nose radius and tool geometry, cutting time, workpiece hardness, stability of the machine tool and the workpiece set up, etc.

Horng[21] developed a model for the prediction of surface roughness followed by an optimization model for the determination of optimal cutting conditions in machining austenitic Hadfield steel. The quadratic model of RSM associated with the sequential approximation optimization (SAO) method was used to find optimum values of machining parameters.

Dureja[23] investigated the effect of cutting speed, depth of cut, workpiece hardness and feed rate on surface roughness and flank wear using a three-level factorial design, during machining of AISI H11 with a coated mixed ceramic tool. The study indicated that feed rate and workpiece hardness are the most significant factors affecting the surface roughness.

Çaydas[24] A correlation between surface roughness and tool wear is proposed for the usual cutting speed ranges. In an original work carried out yo evaluate the effects of the cutting speed, feed rate, depth of cut, workpiece hardness, and cutting tool type on surface roughness, tool flank wear, and maximum tool–chip interface temperature during an orthogonal hard turning of hardened/tempered AISI 4340 steels were investigated.

Aouici[25] studied on machining of slide-lathing grade X38CrMoV5-1 steel treated at 50 HRC by a CBN 7020 tool to reveal the influences of cutting parameters: feed rate, cutting speed and depth of cut on cutting forces as well as on surface roughness. The authors found that tangential cutting force was very sensitive to the variation of cutting depth. It was observed that surface roughness was very sensitive to the variation of feed rate and that flank wear had a great influence on the evolution of cutting force components and on the criteria of surface roughness.

M. N. Islam [28] Feed rate has a dominant effect on surface finish; the interaction between cutting speed and feed rate also plays a major role which is influenced by the properties of work material. With the increase of material hardness the interaction effect diminishes. Surface roughness by itself is not a reliable indicator of machinability, due to non-optimal cutting conditions and interaction effects of additional factors.

Krishankant & Jatin Taneja[30] EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. The bars used are of diameter 44mm and length 60mm. There are three machining parameters i.e. Spindle speed, Feed rate, Depth of cut. Different experiments are done by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Taguchi orthogonal array is designed with three levels of turning parameters with the help of software Minitab 15. In the first run nine experiments are performed and material removal rate (MRR) is calculated

Kamal Hassan[32] There is a number of parameters like cutting speed, feed and depth of cut etc. which must be given consideration during the machining of medium Brass alloy. This study investigates the effects of process parameters on Material Removal Rate (MRR) in turning of C34000. The single response optimization problems i.e. optimization of MRR is solved by using Taguchi method. The optimization of MRR is done using twenty seven experimental runs based on L27 orthogonal array of the Taguchi method. The Material removal rate is mainly affected by cutting speed and feed rate. With the increase in cutting speed the material removal rate is increases & as the feed rate increases the material removal rate is increase.

M.Khaladkar[33] The Experimental investigation conducted to turn AISI 304 austenitic stainless steel using PVD coated cermets by employing Taguchi technique to determine the optimal levels of process parameters. In case of MRR response, depth of cut is dominant one followed by feed. The optimal combination of process parameters parameter is obtained at 150 m/min cutting speed 0.25mm/rev, 2mm depth of cut and 0.4 mm nose radius.

Gap in Literature

The above literature review clearly indicates that the study of feed, speed and depth of cut on cutting force and surface roughness has been very active since the past several decades, but there has been a continuous need to extend this study for the different combinations of tool and work material. The literature review also shows that there is no much of work undertaken with mixed carbide tool and heat resistant alloy combination, despite the fact that it is a widely used combination owing to its industrial applications.

Input parameters preferred - speed, feed rate, depth of cut, coolant used, tool material, tool geometry, rake angles, etc. and

Output parameters preferred- surface roughness, MRR, tool wear rate, cutting forces, residual stresses, etc.
Material preferred - steel alloys, aluminum alloys etc.
Tool material preferred - HSS, carbide, ceramic, CBN, Diamond, etc
Tool edge geometries preferred - ceramic wiper and whisker geometries.
It is observed that the effect on machining process of tool geometry on work piece material like heat resistant superalloy by the selecting various process parameters with the use of empirical approach have not been explored yet, so is interesting to Optimization of Different Machining Parameters of Superalloy material in CNC Turning by Use of Taguchi Method. All these aspects will be addressed in research work.

Chapter 3: PROBLEM IDENTIFICATION AND OBJECTIVES

3.1Defination: This study aims to determine and analyze the effect of the cutting tool edge geometry and cutting parameters (speed, feed, depth of cut) on the cutting forces and surface roughness in turning of Nimonic-80 with Carbide inserts.

3.2 Objectives

1. To Develop Taguchi model for experimentation.
2. To analyze the effect of process parameters viz. speed, feed, depth of cut along with tool edge geometry for cutting forces and surface roughness.
3. To find optimum combination of parameters in order to get the minimum surface roughness & cutting forces.
4. To statistically analyze the response parameters.

Chapter 4: Methodology

4.1 Material Selection

By reviewing the literature survey it has been observed that material from Nickel Chromium based superalloys have less interest for turning. So the material from Nickel alloy family have been consider for further work. These Nickel chromium based alloys are used extensively in applications where heat resistance and/or corrosion resistance is required [36]. This group of alloys are frequently sold under trade name specifications as follows.

1. HASTELLOY
2. INCOLOY
3. INCONEL
4. NICROFER
5. NICROM
6. NIMONIC
7.

Nimonic is a special metal that refers to a family of Nickel based high-temperature low creep superalloys. It consist of more than 50% nickel and 20% chromium with additives as titanium and aluminium.

Due to its ability to sustain very high temperatures, Nimonic alloys is very ideal for use in aircraft parts and gas turbine components such as turbine blades and exhaust nozzles on jet engines, for instance, where the pressure and heat are extreme. It is available in different grades such as Nimonic-75, Nimonic-80, Nimonic-90, Nimonic-105, Nimonic-263.

Nimonic-80 was used for the Turbine blades on the Rolls-Royce Nene and de Haviland Ghost. Nimonic-90 used in the Bristol Proteus, and Nimonic 105 in the Rolls-Royce Spey aviation gas turbines. Also Nimonic 263 was used in the combustion chambers of the Bristol Olympus used on the Concorde supersonic airliner.

By studying of Nimonic Family, the Nimonic-80 has been taken for experimental work because of its own advantages, easily availability, lower cost and less time delivery as compared to others.

Nimonic-80, a nickel based super-alloy having 60% Ni, 19.3% Cr, 3% Fe, 2% Co, 2.7% Ti, 1.4% Al, was taken as a work material in the form of a round bar having 50mm length and 25 mm diameter. The composition and physical properties of the material are given in following table 4.1.1 and 4.1.2 respectively [36].

Material	**Percentage (%)**
Ni	69
Cr	18-21
Fe	<3
Co	<2
Ti	1.8-2.7
Al	1.0-1.8
Others	Remainder

Table 4.1.1: Composition of Nimonic-80

Hardness (Rockwell)	32 RH
Density	8.18 gm/cm3
Modulus of Elasticity	213 Gpa
Yield Stress	270 N/mm2
Specific heat	465 J/Kg °C
Thermal Conductivity	79.7 W/m °C
Melting point	1370 °C ie. 2500°F

Table 4.1.2: Physical properties of Nimonic-80

4.2 Cutting Tool Selection

For machining like turning there are lots of cutting tool materials are available like HSS, Carbide, Ceramic, CBN, Cermet and Diamond cutting tool.

- HSS

They are todays most commonly used cutting tool material. These tools are unstable and inexpensive as compared. They retain hardness at moderate temperatures. They are having hardness to about HRC 67. Sharp cutting edges can be possible to made by these tools.

- Carbide

Carbide inserts are at least 25-100 times more resistant to wear than High Speed Steel tools. Also they are used in machining tough material such as carbon steel or stainless steel also in the situation where other tools are wear out. It will give better finish on the part and allow faster machining. They also withstand to higher temperatures than HSS tools.

- Ceramic

They are stable and moderately inexpensive as compared. They are chemically inert and extremely resistant to heat. These tools are usually desirable in high speed application. They are unpredictable under unfavorable conditions. They are having hardness upto about HRC 93. Sharp cutting edges and positive rake angles are to be avoided in these tools.

- CBN

They are nothing but the Carbon Boron Nitride. It is stable and expensive also it is the second hardest substance known. It offers extremely high resistance to abrasion at the expense of much toughness. It is generally used in a machining process called hard machining. It is used almost exclusively on turning tool bits. They are having hardness higher than HRC95. Sharp edges generally not recommended.

- Cermet

They are stable and moderately expensive. They are another cemented material based on titanium carbide. It provides higher abrasion resistance compared to tungsten carbide at the expenses of some toughness. It is extremely high resistance to abrasion. They are having hardness up to about HRC 93. Generally sharp cutting edges does not recommended by these tools.

- Diamond

They are stable and very expensive, also the hardest substance known till date. It is having superior resistance to abrasion but also not suitable for steel machining. It is used where abrasive materials would wear. They Used almost exclusively on turning tool bits also it can be used for coating on various kinds of tools. Sharp edges generally not recommended by these tools.

In this work the material used was the Nimonic-80, having hardness 32 HRC, melting point 1370ºC. It is highly temperature resistant can be used where high temperature applications are there. So for machining this type of material the hard cutting tool material was used as it can allow the faster machining, also provide better surface finish. In this case the carbide tool has been concerned for work.

Cutting Tool Geometry

Cutting tool geometry plays a vital role in case of metal cutting. The design of cutting edge geometry and its influence on machining performance has been a research topic in the area of metal cutting for long time. Cutting edge preparation has a significant effect on the tool life. If a tool is with improper edge it will fail quickly. So it is important to consider the tool-edge effect in order to better understand the chip formation mechanism and accurately predict machining performances, such as cutting forces, cutting temperatures, tool wear, surface finish and the machined surface integrity.

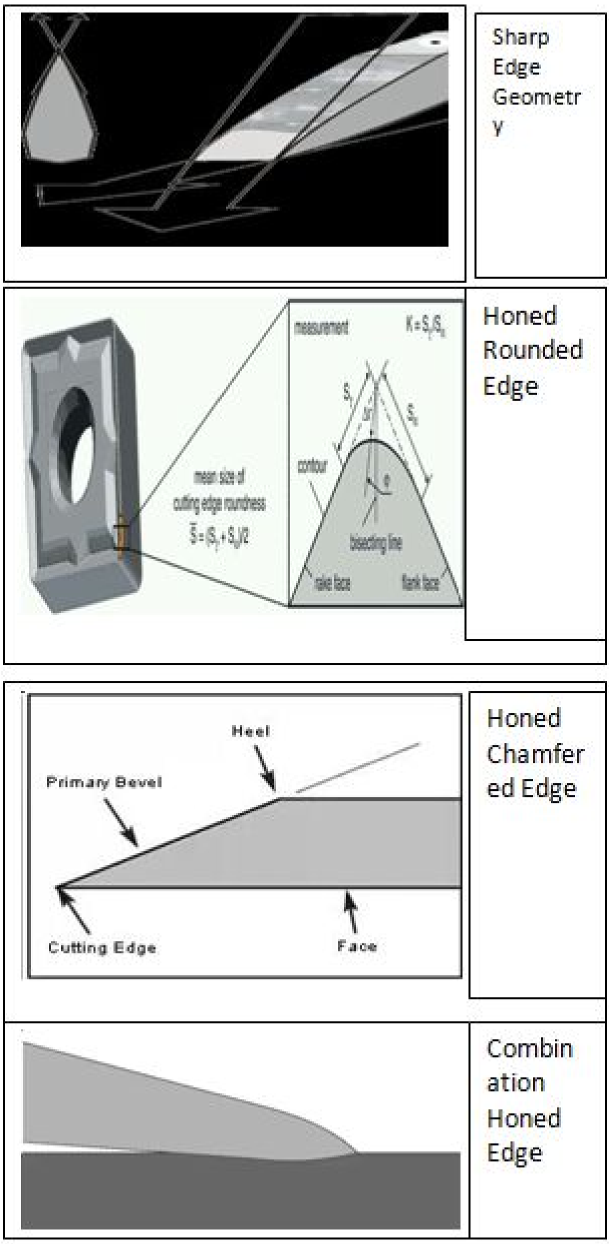


Fig 4.2: Cutting Tool Edge Geometry[29

In the carbide inserts few cutting edge geometries are available as follows. Fig 4.2 shows the specification of various tool geometries.

1. Sharp Edge Geometry
2. Honed Rounded Edge
3. Honed Chamfered Edge
4. Combination Honed Edge

From these geometries the two geometries was taken for experiment as they are easily available in the market those are

- Honed Rounded Edge
- Combination Honed Edge

The cutting tools selected was carbide insert tool from ‘Taegutech’ Tool Suppliers company. The detailed description given as follows.

Table 4.2: Cutting Tool Specifications

Sr. No./ Description	Type of Tool	Cutting Edge Length	Cutting Edge Thickness	Nose Radius	Grade
1.	TNMG	16	04	08	AC3000
2.	TNMG	16	04	08	AC304

Fig.4.2 a. Carbide Insert AC304 [35]

Fig.4.2 b. Carbide Insert AC3000 [35]

4.3 Optimizing Parameters

4.3.1 Process Parameters

1. Depth of cut (*d*): The depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of the work piece in mm.[1]
2. Cutting speed - The cutting speed of a tool is the speed at which the metal is removed by the tool from the work material.

   In a lathe it is the peripheral speed of the work part in m/min.

   V = лDN/1000 (m/min)[1]

   Where D, N are diameter of work piece (mm) and cutting speed (rpm) respectively.[1]

3. Feed rate - The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in inches per minute (IPM) and is the product of the cutting feed (IPR) and the spindle speed (RPM).[1]

4. Cutting Tool Geometry – Different tool edge geometries have taken into consideration to observe the effect of that on the output.[1]

4.3.2 Response Parameters

1. Surface Finish: The degree of smoothness of a part's surface after it has been manufactured. Surface finish is the result of the surface roughness, waviness, and flaws remaining on the part.
2. Cutting Forces: Cutting forces are necessary for evaluation of power consumption during machining (choice of the electric motor). They are also used for design of machine tool components and the tool body. Cutting forces influences the deformation of the work piece machined, its dimensional accuracy, machine stability and chip formation.

Table 4.4.1: Process parameter and their levels

Sr. No.	Parameters	Symbol	Unit	Level 1	Level 2	Level 3
1.	Tool Geometry	A		A1 (Honed Rounded Edge)	A2 (Combination Honed Edge)	
2.	Cutting Speed	B	m/min	50	75	100
3.	Feed Rate	C	mm/rev	0.2	0.3	0.4
4.	Depth Of Cut	D	Mm	0.5	1.0	1.5

4.4 Design Of Experiment

4.4.1 Process Parameters and their Levels

Before implementing the optimization procedure selection of control factors and its levels, responses are important to design the experiment as mentioned in the table 4.4.1.

The first parameter selected was Tool Geometry and it consist of two levels of experiment A1 (Honed Rounded Edge) and A2 (Combination Honed Edge). Second parameter selected was cutting speed consist of three levels and having range 50, 75, 100 m/min. Third parameter selected was Feed rate consist of three levels and having range 0.2, 0.3, 0.4 mm/rev. Fourth parameter selected was Depth of cut consist of three levels of experiment and range 0.5, 1.0, 1.5 mm.

4.4.2 Taguchi method

Taguchi methods are statistical methods developed to improve the quality of manufactured goods and more recently also applied to engineering, biotechnology, marketing and advertising [19]. The work of Taguchi includes three principal contributions to statistics:

- A specific loss function , Taguchi loss function;
- The philosophy of off-line quality control; and

- Innovations in the design of experiments.

Taguchi philosophies are mostly used in engineering optimization processes. It should be carried in three step approach i.e. system design, parameter design, tolerance design. The system design involves, scientific and engineering principles and know how are used to create a prototype of the product that will meet functional requirements. In case of Parameter design we optimize the settings of process parameter values for improving performance characteristics [19]. Taguchi also defined a performance measure known as the signal to noise ratio (S/N) and aims to maximize it by selecting parameter levels properly.[19]

- Nominal is the best:

S/NT = 10 log $(\hat{y}/s2)$ [19]

- Larger is the better (maximize):

S/NL= -10log $1/\frac{1}{y}\sum_i^n \frac{1}{yi^2}$ [19]

- Smaller is better (minimize):

S/NS= -10log $1/y\,\frac{1}{y}\sum_i^n 1yi^2$ [19]

Where ŷ the average of observed data is, Sy^2 is the variance of y, n the no. of observations and Y is the observed data.

4.4.3 Selection of Orthogonal Array

For selecting an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to find out which level is better. In this study, an L18 orthogonal array was used. This array has degrees of freedom 3 and it can handle three-level process parameters. Each cutting parameter is assigned to a column and 18 cutting parameter combinations are available. Therefore, 18 experiments are required to study the entire parameter space using the L18 orthogonal array. As first parameter has two levels and remaining three levels, so parameter was analysed at three levels in order to explore nonlinear relationship of process parameter. The variation of response is examined using an appropriately chosen S/N ratio, depending on the objective function. The present study has been done through the following plan of experiment as shown in table 4.4.2.

Table 4.4.2: DOE as per Taguchi L18

Sr. No.\Exp.	A (Cutting Tool Geometry)	B (Cutting Speed)	C (Feed Rate)	D (Depth of Cut)
1.	A1	50	0.2	0.5
2.	A1	50	0.3	1.0
3.	A1	50	0.4	1.5
4.	A1	75	0.2	0.5
5.	A1	75	0.3	1.0
6.	A1	75	0.4	1.5
7.	A1	100	0.2	1.0
8.	A1	100	0.3	1.5
9.	A1	100	0.4	0.5
10.	A2	50	0.2	1.5
11.	A2	50	0.3	0.5
12.	A2	50	0.4	1.0
13.	A2	75	0.2	1.0
14.	A2	75	0.3	1.5
15.	A2	75	0.4	0.5
16.	A2	100	0.2	1.5
17.	A2	100	0.3	0.5
18.	A2	10	0.4	1.0

4.5 Experimentation

The cutting experiments were carried out on a MTAB CNC Lathe under different cutting conditions are shown in Fig. 4.5. Machining tests were performed on an Nimonic bar having Diameter Φ 25mm. Tool material for this study was Carbide having different tool geometry A1, A2 respectively. A strain gauge type Dynamometer was used to measure axial force (Fx), thrust force (Fy) and Tangential force (Fz). Taguchi parameter optimization method was used to evaluate the best possible combination for minimum cutting force during turning operation. Cutting force and surface roughness according to cutting parameters were measured through the external cylindrical turning based on the experiment plan.

The tool was fixed to the dynamometer which was fixed to the tool post. Surface Roughness Tester was used to measure the Ra value for each machined surface. Analysis of the data was done using Taguchi optimization tool.

4.5.1 CNC Lathe Machine Specification

The industrial type design slant bed turning centre with 8 station programmable turret machine operated by Siemens control system [37].

Technical Specification:

- Capacity- 1. Chuck size- 135 mm (Hydraulic)

2. Maximum Turning Diameter- 210 mm
3. Maximum Turning Length- 200 mm
4. Bed- Slant Bed 45 Deg
5. No. of Axes- 2

- Spindle- 1. Spindle speed Range – 150 to 6000 RPM

2. Spindle Motor- AC Servo Spindle Motor
3. Spindle Motor Capacity- 5.5 Kw, 7.4 HP

Axes- 1. X- Axis Travel – 120 mm
2. Z- Axis Travel- 225 mm
3. Feed Rate- 0 to 10000 mm/min

4.5.2. Dynamometer

While during machining the cutting tool exerts force on the work piece and similar force is experienced by the tool also. Empirical relationship to calculate the cutting forces are no more relied upon to determine the minimum cutting condition. For Optimization of cutting parameters the accurate measurement of forces requires for which we use a device called dynamometer. It is capable of measuring components of forces in a particular coordinate system. It is an important tool with wide application in manufacturing and research.

A dynamometer design involves a compromise between a structure that allows highest possible sensitivity at sufficient stiffness and rigidity so that the geometry of the cutting process is maintained. At the same time the dynamometer structure should maintain a high natural frequency to minimize chattering. Cutting forces cannot be measured directly. Whenever a force acts on a material it undergoes a certain deformation, which can be measured and hence the acting force can be accordingly derived. Therefore, the principle on which all the dynamometers are designed is to measure the deflection or strains induced in the dynamometer structure caused by the resultant cutting force. The setup of the dynamometer on the CNC Turning machine as shown in fig. 4.5.2.

Fig. 4.5.2: View of Cutting Zone

4.5.3 Conducting Experiments

Initially the technical parameters were converted into machining parameters. Such as cutting speed in the mm/min was converted into the spindle speed in RPM by using the Formula V= лDN/1000. Then feed rate was changed into machining feed using formula (F×N). Dynamometer setup was done on the machine with respect the workpiece. The workpeice of the length of 50 mm was centered and fixed on the chuck properly. Then according to the design of experiment table 4.4.2 the values of cutting parameters was adjusted in the lathe machine. The workpiece was given initial roughing cycle so that it will become plane and uniform.

While performing the first experiment there was some difficulty arrived regarding values of parameters. The cutting speed was lesser and depth of cut was higher because of it the cutting tool tip became blunt and workpiece became scrap. Then by reconsideration of the parameters and mechanical properties of the tool material new set of values of parameters have been decided. Those new values are given in the table 4.5.3.

Table 4.5.3: Reorganized Observation

Sr. No.\Exp.	A (Tool Geometry)	B (Cutting Speed)	C (Feed Rate)	D (Depth of Cut)
1.	A1	100	0.1	0.4
2.	A1	100	0.2	0.8
3.	A1	100	0.3	1.2
4.	A1	125	0.1	0.4
5.	A1	125	0.2	0.8
6.	A1	125	0.3	1.2
7.	A1	150	0.1	0.8
8.	A1	150	0.2	1.2
9.	A1	150	0.3	0.4
10.	A2	100	0.1	1.2
11.	A2	100	0.2	0.4
12.	A2	100	0.3	0.8
13.	A2	125	0.1	0.8
14.	A2	125	0.2	1.2
15.	A2	125	0.3	0.4
16.	A2	150	0.1	1.2
17.	A2	150	0.2	0.4
18.	A2	150	0.3	0.8

First experiment was carried on the workpiece by giving desired value of parameters. Dynamometer was already mounted which help to carry out the cutting forces measurement. They were displayed on the screen with its graphs showing values of Axial Force (Fx), Thrust Force (Fy) and Tangential Force (Fz). Report data was stored on the system and setup for new experiment. The remaining experiments were carried one by one by order. The shape of workpiece after machining is shown in fig. 4.5.3. Dimensions are in mm.

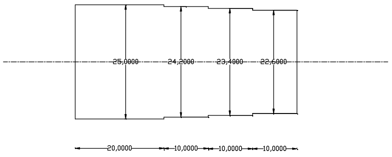


Fig. 4.5.3: Finished workpiece After Machining

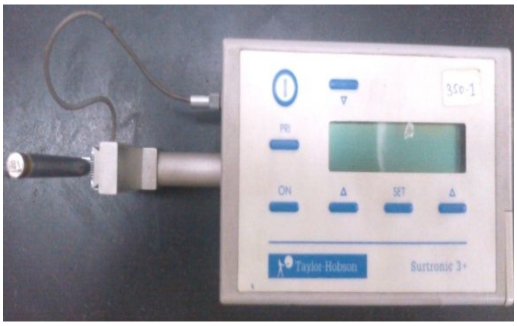


Fig. 4.5.4: Surface Roughness Tester

4.5.4 Surface roughness measurement

The instrument used to measure surface roughness was “Time surface roughness tester Surtronoc-3”. Surface roughness readings were recorded at three locations on the work piece and the average value was used for analysis. Specifications of Instrument used:

Measuring Conditions:

Probe type:	TKU300
Measuring range:	800 µm
LV:	waveline 60
Transverse length:	4.80 mm
Speed:	0.50 mm/sec
Lc:	0.800 mm

Chapter 5: EXPERIMENTAL OBSERVATION

The observed values of Axial force, Thrust force, Tangential force and Surface Roughness was measured and written as shown in the table 5.1.

Table 5.1: Observation Table

Sr. No.\Exp.	**A (Tool Geometry)**	**B (Cutting Speed)**	**C (Feed Rate)**	**D (Depth of Cut)**	**Axial Force**	**Thrust Force**	**Tangential Force**	**RA**
1.	A1	100	0.1	0.4	59	54	101	0.54
2.	A1	100	0.2	0.8	530	399	425	1.55
3.	A1	100	0.3	1.2	831	437	624	3.76
4.	A1	125	0.1	0.4	163	71	111	0.94
5.	A1	125	0.2	0.8	631	491	531	2.23
6.	A1	125	0.3	1.2	1016	523	758	4.86
7.	A1	150	0.1	0.8	489	580	614	1.82
8.	A1	150	0.2	1.2	855	885	1100	4.32
9.	A1	150	0.3	0.4	301	367	178	5.2
10.	A2	100	0.1	1.2	468	206	446	1.13
11.	A2	100	0.2	0.4	262	194	117	1.55
12.	A2	100	0.3	0.8	672	459	383	2.7
13.	A2	125	0.1	0.8	421	277	326	1.04
14.	A2	125	0.2	1.2	856	566	862	3.44
15.	A2	125	0.3	0.4	359	183	58	2.89
16.	A2	150	0.1	1.2	584	529	829	1.47
17.	A2	150	0.2	0.4	293	457	455	1.7
18.	A2	150	0.3	0.8	690	776	695	3.14

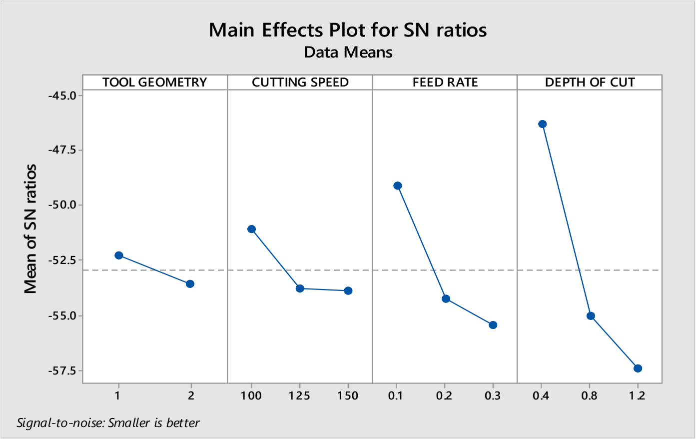
The cutting forces and surface roughness data was collected according to the Taguchi analysis method of the Minitab 17 software. Minitab 17 software was used as it provides an easy method to generate, alter and revise graphs. Also it provides an active link between a graph and its worksheet thus helps in updating the graph automatically whenever the data is altered.

Computation of (Signal-to-Noise Ratio) S/N ratio of experimental data table has been done. For calculating S/N ratio of Ra and force a Smaller-the-Better (SB) criterion has been selected.

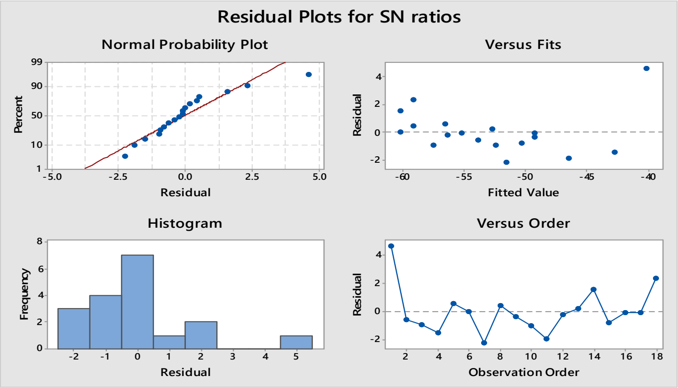
Chapter 6: Results & Discussion

Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value The transformation of the repetition data in a trial into a consolidated single value called the S/N ratio. The term ‘S’ represents the mean value for the output characteristic while the ‘N’ represents the undesirable value for the output characteristic. So the S/N ratio represents the amount of variation present in the quality characteristic. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. In this paper, the cutting parameter design by the Taguchi method is adopted to obtain optimal machining performance in turning.

6.1 Result analysis for Axial Force



Graph 6.1.1: Main effect plot for S/N ratio



Graph 6.1.2: Residual effect plot for S/N ratio

Figure-6.1.1 shows the main effect plot and figure 6.1.2 shows residual plot for S/N ratio respectively for Tool geometry, cutting speed, feed rate and depth of cut. According to Main effect plot the optimal condition for minimum Axial force are:

- Tool geometry no. 2
- Cutting speed at level 3 (150 m/min)
- Feed rate at level 3 (0.3 mm/rev)
- Depth of cut at level 3 (1.2 mm)

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for Axial force are shown in Fig. 6.1.2. The points are distributed frequently on one side normally from straight line implying that some errors are found normally. From Fig. 6.1.2, it can be concluded that all the some values are out of the control range, there is no obvious pattern in case of fitted values and no unused structure found.

Table 6.1.1: Analysis of Variance for SN ratios

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	
Tool Geometry	1	7.124	7.124	7.124	1.62	0.052	Significant
Cutting speed	2	30.00	30.00	15.00	3.40	0.026	Significant
Feed rate	2	135.145	135.145	67.572	15.33	0.017	Significant
Depth of Cut	2	407.901	407.901	203.950	46.27	0.014	Significant
Residual Error	10	44.080	44.080	4.408			
Total	17	624.250					
	S= 2.100	R-sq= 90.9%	R-sq (adj)= 88%				

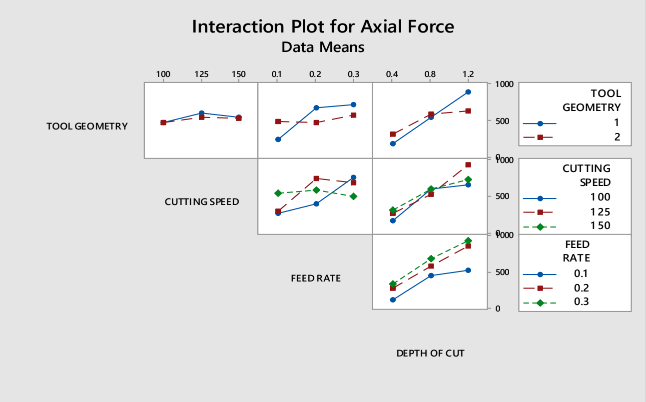
Table 6.1.2: Response Table for Signal to Noise Ratios Smaller is better

Level	Tool Geometry	Cutting speed	Feed Rate	Depth of Cut
1	-52.30	-51.10	-49.11	-46.34
2	-53.56	-53.77	-54.25	-55.01
3		-53.91	-55.42	-57.43
Delta	1.26	2.80	6.31	11.09
Rank	4	3	2	1

It can be seen from Table 6.1.2 and according to the rank value for each control factor that the depth of cut had the strongest influence on axial force followed by feed rate, cutting speed and last by tool geometry. From Table 6.1.1, analysis of variance ANOVA, It can be found that depth of cut and feed rate are the significant parameters and cutting speed is also a good significant factor and Tool geometry is less significant.

Interaction plot

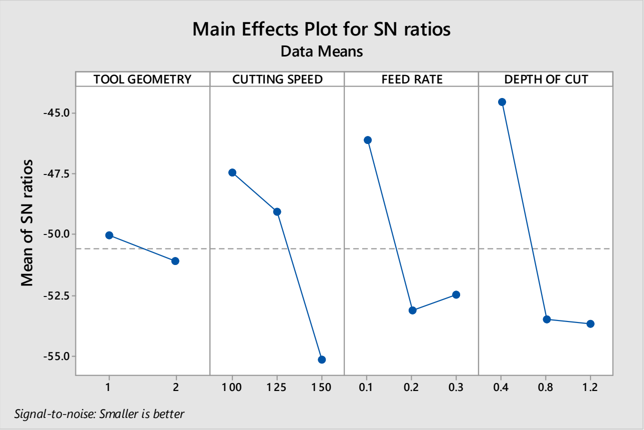
The plots show the variation of individual response with the four parameters i.e. cutting speed, feed, depth of cut and Tool Geometry separately. In the plots, the x-axis indicates the value of each parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response.



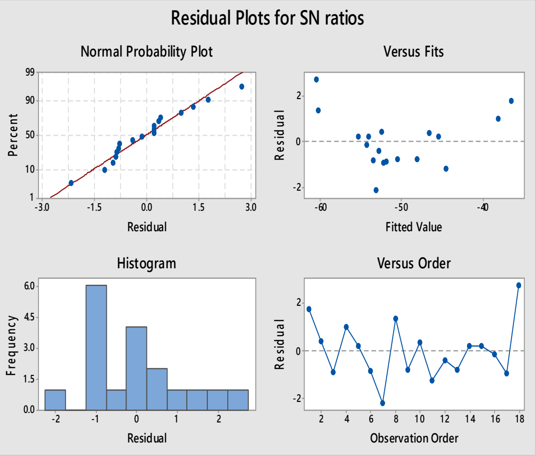
Graph 6.1.3: Interaction plot for Axial Force

Results of interaction plots for Axial force (Figure-6.1.3) show that there is a less significant interaction in between tool geometry Vs cutting speed. No interaction is observed in between depth of cut Vs feed rate. There is significant interaction between tool geometry Vs depth of cut, between feed rate Vs depth of cut. Parallel lines show that there is no interaction effect between the parameters.

6.2 Results analysis for Thrust Force



Graph 6.2.1: effect plot for S/N ratio



Graph 6.2.1: Residual effect plot for S/N ratio

Figure-6.2.1 shows the main effect plot and figure 6.2.2 shows residual effect plot for Mean and S/N ratio respectively for Tool geometry, cutting speed, feed rate and depth of cut. According to Main effect plot the optimal condition for minimum Thrust force are:

- Tool geometry no. 2
- Cutting speed at level 3 (150 m/min)
- Feed rate at level 2 (0.2 mm/rev)
- Depth of cut at level 3 (1.2 mm)

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for Thrust force are shown in Fig. 6.2.2. That some errors are founded because of some points are distributed away from straight line. There is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

Table 6.2.1: Analysis of Variance for SN ratios

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	
Tool Geometry	1	5.222	5.222	5.22	2.18	0.071	InSignificant
Cutting speed	2	198.21	198.218	99.109	41.30	0.017	Significant
Feed rate	2	181.23	181.233	90.617	37.76	0.013	Significant
Depth of Cut	2	327.528	327.528	163.764	68.25	0.002	Significant
Residual Error	10	23.996	23.996	2.400			
Total	17	624.250					
	S= 1.549	R-sq= 86.7%	R-sq (adj)= 84.5%				

Table 6.2.2: Response Table for Signal to Noise Ratios
Smaller is better

Level	Tool Geometry	Cutting speed	Feed Rate	Depth of Cut
1	-50.02	-47.46	-46.09	-44.53
2	-51.10	-49.06	-53.13	-53.50
3		-55.16	-52.46	-53.65
Delta	1.08	7.70	7.04	9.13
Rank	4	2	3	1

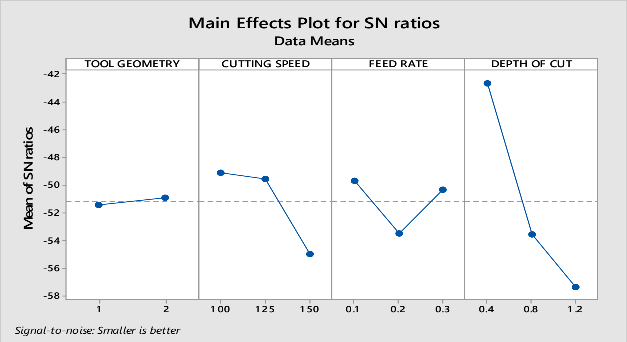
It can be seen from Table 6.2.2 and according to the rank value for each control factor that the depth of cut had the strongest influence on Thrust force followed by cutting speed and feed rate and last by tool geometry. From Table 6.2.1 analysis of variance ANOVA, It can be found that cutting speed and depth of cut are the significant cutting parameters for thrust force. The change of the Tool geometry is less significant.

Interaction Plot

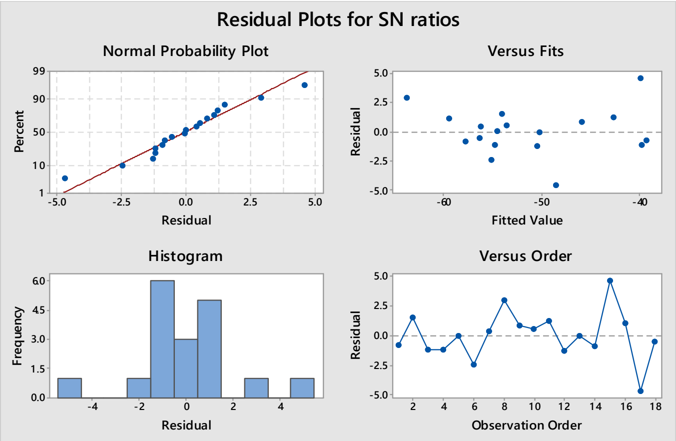
Graph 6.2.3: Interaction plot for Thrust Force

Results of interaction plots for Thrust force (Figure-6.2.3) show that there is There is good significant interaction between tool geometry Vs depth of cut also between tool geometry Vs feed rate. There is no interaction in between tool geometry Vs cutting speed. Similar effect is observed in between cutting speed Vs depth of cut.

6.3 Result analysis for Tangential force



Graph 6.3.1: Main effect plot for S/N ratio



Graph 6.3.2: Residual effect plot for S/N ratio

Figure-6.3.1 shows the main effect plot and figure 6.3.2 shows residual effect plot for Mean and S/N ratio respectively for Tool geometry, cutting speed, feed rate and depth of cut. According to Main effect plot the optimal condition for minimal Tangential force are:

- Tool geometry at no. 1
- Cutting speed at level 3 (150 m/min)
- Feed rate at level 2 (0.2 mm/rev)
- Depth of cut at level 3 (1.2 mm)

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for Tangential force are shown in Fig. 6.3.2. These are generally fall on a straight line implying that errors are distributed normally and also the residual analysis does not indicate any model inadequacy.

Table 6.3.1: Analysis of Variance for SN ratios

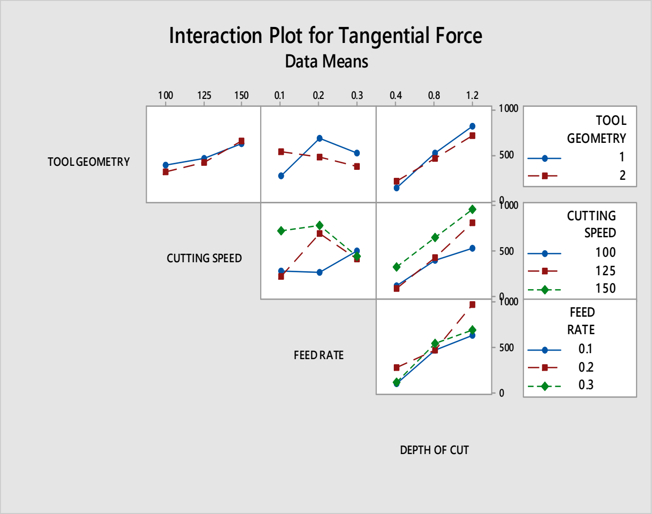
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	
Tool Geometry	1	1.140	1.140	1.140	0.16	0.205	InSignificant
Cutting speed	2	129.509	129.509	64.755	9.27	0.037	Significant
Feed rate	2	49.355	49.35	24.677	3.53	0.025	Significant
Depth of Cut	2	705.548	705.548	352.774	50.49	0.022	Significant
Residual Error	10	69.865	69.865	6.987			
Total	17	955.417					
	S= 2.643	R-sq= 90.7%	R-sq (adj)= 87.6%				

Table 6.3.2: Response Table for Signal to Noise Ratios
Smaller is better

Level	Tool Geometry	Cutting speed	Feed Rate	Depth of Cut
1	-51.46	-49.10	-49.73	-42.63
2	-50.96	-49.54	-53.52	-53.60
3		-55.00	-50.38	-57.40
Delta	0.50	5.90	3.79	14.77
Rank	4	2	3	1

It can be seen from Table 6.3.2 and according to the rank value for each control factor that the depth of cut had the strongest influence on tangential force followed by cutting speed and last by feed rate. Similar in case of main effects plot for S/N ratio for Tangential force. From Table 6.3.1 analysis of variance ANOVA, It can be found that depth of cut, cutting speed and feed rate are the significant cutting parameters for tangential force. The change of the Tool geometry is not significant.

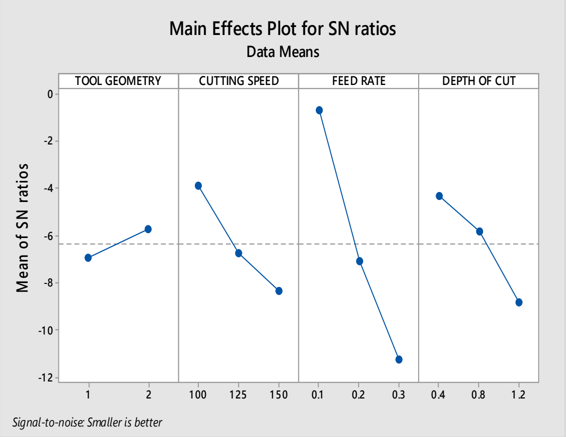
Interaction Plot



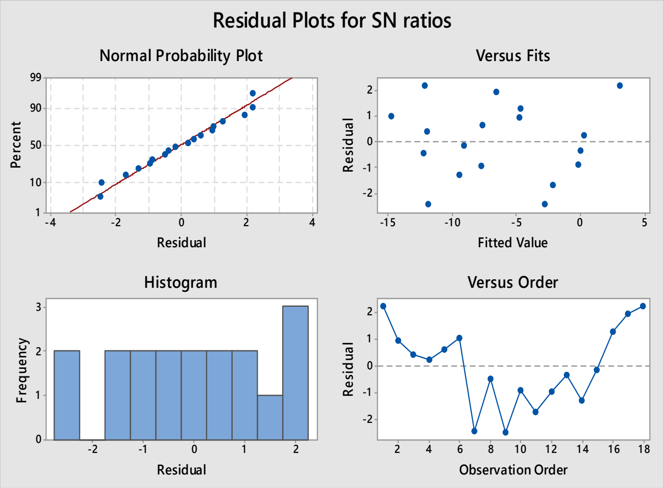
Graph 6.3.3: Interaction plot for Tangential Force

Results of interaction plots for Tangential force (Figure-6.3.3) show that there is no interaction effect in between depth of cut Vs cutting speed. Similar effect is observed in between cutting speed Vs feed rate, between cutting speed Vs depth of cut , good significant interaction feed rate Vs depth of cut. There is good interaction between tool geometry Vs depth of cut also between cutting speed Vs depth of cut. Parallel lines show that there is no interaction effect between the parameters.

6.4 Result analysis for Ra Value



Graph 6.4.1: Main effect plot for S/N ratio



Graph 6.4.2: Residual effect plot for S/N ratio

Figure-6.4.1 shows the main effect plot and figure 6.4.2 shows residual effect plot for Mean and S/N ratio respectively for Tool geometry, cutting speed, feed rate and depth of cut. According to Main effect plot the optimal condition for minimum surface roughness are:

- Tool geometry no. 1
- Cutting speed at level 3 (150 m/min)
- Feed rate at level 3 (0.3 mm/rev)
- Depth of cut at level 3 (1.2 mm)

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for surface roughness are shown in Fig. 6.4.2. These are generally fall on a straight line implying that errors are distributed normally. From Fig. 6.4.2, it can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

Table 6.4.1: Analysis of Variance for SN ratios

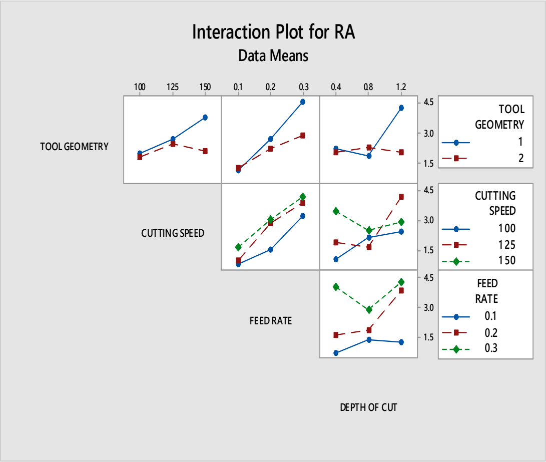
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	
Tool Geometry	1	6.327	6.327	6.327	1.75	0.046	Significant
Cutting speed	2	60.770	60.770	30.385	8.38	0.016	Significant
Feed rate	2	339.030	339.03	169.515	46.78	0.003	Significant
Depth of Cut	2	63.293	63.293	31.647	8.73	0.007	Significant
Residual Error	10	36.238	36.238	3.624			
Total	17	505.659					
	S= 1.904	R-sq= 90.8%	R-sq (adj)= 87.8%				

Table 6.4.2: Response Table for Signal to Noise Ratios
Smaller is better

Level	Tool Geometry	Cutting speed	Feed Rate	Depth of Cut
1	-6.92	-3.90	-0.67	-4.34
2	-5.74	-6.74	-7.10	-5.81
3		-8.35	-11.22	-8.84
Delta	1.18	4.44	10.54	4.50
Rank	4	3	1	2

It can be seen from Table 6.4.2 and according to the rank value for each control factor that the feed rate had the strongest influence on surface roughness followed by depth of cut and cutting speed. Tool geometry also have its impact on surface roughness. From the main effects plot for S/N ratio for surface roughness, the surface roughness appears to be an almost linear increasing function of feed rate (F) and decreasing function of cutting speed (S).

From Table 6.4.1, analysis of variance ANOVA for surface roughness, It can be found that cutting speed and feed rate are the significant cutting parameters for surface roughness. The change of the Tool geometry is also ignificant factor.



Graph 6.4.3: Interaction plot for Surface Roughness

Results of interaction plots for R_a values (Figure-6.4.3) show that There is good interaction between tool geometry Vs depth of cut also between cutting speed Vs depth of cut. Parallel lines show that there is no interaction effect between the parameters. There is no interaction between tool geometry Vs cutting speed, similar in case of cutting speed Vs feed rate. a less significant interaction effect in between tool geometry Vs feed rate.

Chapter 7: Conclusions

The tests of straight turning carried out on Nimonic-80, machined by two carbide tools having different tool edge geometry, enabled us to study the influence of the following parameters: feed rate, cutting speed and depth of cut on cutting forces and surface roughness. The conclusions of research are as follows.

- Axial force have significant parameters, depth of cut is the varying parameter and it is mostly affect on axial force.
- Tangential cutting force is very sensitive to the variation of cutting depth what affects the feed (axial) forces in a considerable way.
- Thrust force is dominating compared to both others and that for the cutting speed most affective parameter.
- Surface roughness is very sensitive to the variation of the feed rate and it affects most significantly.
- Taguchi technique has the advantage of investigating the influence of each machining variable on the values of technological parameters.
- Depth of cut is the most significant factor with 31.57% contribution in the total variability of model (*T*), whereas feed rate has a secondary contribution of 5.83% in the model.

Future Scope

- This work uses the parameters cutting speed, feed rate, depth of cut and cutting tool edge geometry to find the optimum condition for better surface finish and to reduced forces. This work may be continued by performing full factorial experiments using RSM Tool.
- The different types of tool material like Ceramic and Diamond cutting tool can be used for better tool wear rate.
- Different Tool nose radius can be used for better performance with Nimonic-80.

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