“Optimisation of Cutting Parameters during CNC Turning of AISI 304 Austenitic Stainless Steel”

Major project-II

Submitted to Delhi Technological University in partial fulfilment of the requirement for the award of Degree of

Master of Technology

In

Production Engineering

SUBMITTED BY-

MD JAMIL AKHTAR

2K15/PIE/08

UNDER SUPERVISION OF

Dr. Ranganath M Singari	Dr. R.S Mishra
(Professor)	(Professor and HOD)
Mechanical Department	Mechanical Department

Department of Mechanical Engineering

Delhi Technological University

(Formerly DELHI COLLEGE OF ENGINEERING)

Bawana road, Delhi -110042

CERTIFICATE

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly DELHI COLLEGE OF ENGINEERING)

This is to certify that report entitled **"Optimisation of Cutting Parameters during CNC Turning Of AISI 304 Austenitic Stainless Steel" by MD JAMIL AKHTAR** in the requirement of the partial fulfilment for the award of Degree of **Master of Technology (M.Tech)** in **Production Engineering(PIE)** at **Delhi Technological University**. This work was completed under my supervision and guidance.

Dr. Ranganath M. Singari

(Professor)

Mechanical Department

Delhi technological university

Delhi

Dr. R.S Mishra

(Professor and HOD)

Mechanical Department

Delhi technological university

Delhi

DECLARATION

I declare that the work presented in this thesis titled **"Optimisation of Cutting Parameters during CNC Turning Of AISI 304 Austenitic Stainless Steel"**, submitted to Department of Mechanical Engineering, is an authentic record of my own work carried out under the supervision of **Prof. Ranganath M. Singari** and **Prof. R.S Mishra**,(Prof. and HOD) Department of Mechanical Engineering, Delhi technological university, Delhi.

This report does not, to the best of my knowledge, contain part of my work which has been submitted for the award of any other degree either of this university or any other university without proper citation.

Date:

Place: DTU, Delhi Signature of candidate

ACKNOWLEDGEMENT

First, I would like to express my gratitude to God for giving me ideas and strengths to make my dreams true and accomplish this thesis.

To achieve success in any work, guidance plays an important role. It makes us put right amount of energy in the right direction and at right time to obtain the desired result. Express my sincere gratitude to my guide, **Dr. Ranganath M. Singari** (Professor) and **Dr. R.S Mishra**, (Professor and HOD) Mechanical Engineering Department for giving valuable guidance during the course of this work, for his ever encouraging and timely moral support.

I am greatly thankful to **DR. R. S. MISHRA**, Professor and Head, Mechanical Engineering Department, Delhi Technological University, for his encouragement and inspiration for execution of the this work. I express my feelings of thanks to the entire faculty and staff, Department of Mechanical Engineering, Delhi Technological University, and Delhi for their help, inspiration and moral support, which went a long way in the successful completion of my report work.

MD JAMIL AKHTAR

(Roll No-2K15/PIE/08)

ABSTRACT

In this study, the effect of important parameters of machinability like material removal rate and surface roughness were studied. optimization of machining parameters in turning of AISI 304 austenitic stainless steel using cemented carbide tools. During the experiment, process parameters such as speed, feed and depth of cut are used to explore their effect on the surface roughness (R_a) and Material Removal Rate(MRR) of the work piece. The experiments have been conducted using Orthogonal Array(OA) (Taguchi) design in the Design of Experiments (DOE) on Computer Numerical Controlled (CNC) lathe. Further, the analysis of variance (ANOVA) was used to analyze the influence of process parameters and their interaction during machining. From the analysis, it is observed that the Speed is the most significant factor that influences the surface roughness followed by feed and Depth of cut. The optimum cutting speed the impact of cutting speed, Feed and Depth of cut on Material Removal Rate(MRR) and surface roughness have been studied during turning an AISI 304 austenitic stainless steel using cemented carbide cutting tools.

CONTENTS

LIST OF FIGURES

LIST OF TABLE

NOMENCLATURE

AISI	American Iron and Steel Institute
SS	Stainless Steel
CNC	Computer Numerical Control
BUE	Built up Edge
RPM	Revolution per Minute
ANOVA	Analysis Of Variance
MRR	Material Removal Rate
S/N	Signal to Noise
CVD	Chemical Vapour Deposition
RSM	Response Surface Methodology
OA	Orthogonal Array
ANN	Artificial Neural Network
DOC	Depth of Cut
Al	Alluminium
Ra	Surface Roughness
DOF	Dedree of Freedom
SS	Sum of squares
MS	Mean square

CHAPTER 1

INTRODUCTION

1.1 . General

A manufacturing engineer is often expected to utilize experience and to publish shop guidelines for determining the proper machining parameter to achieve specified level of performance. This must be done in a timely manner to avoid production delays, effectively to avoid defects and the produced parts monitored for quality.

CNC Turning is one of the most commonly used for its flexibility and versatility that allows manufacture of products of Rounded shapes in shorter time at reasonable cost and good finish. The surface quality of products is generally determined in terms of the measured surface roughness. Surface roughness and material removal rate is generally dependent on the cutting parameters such as: cutting speed, feed rate and depth of cut. Right selections of these cutting parameters are essential in order to produce components with good surface finish and high tolerance in least time. High material removal rate is required in order to decrease the machining time. In the last few decades, a lot of work has been carried out to improve the product quality and efficiency in machining. Still many aspects related to the domain of this study are yet to be explored.

Many parts are designed such that they must be processed on turning machines in at least one stage of their fabrication. CNC Turning is widely used for its flexibility and versatility that allows manufacture of products in less time at reasonable cost and good surface finish. It is generally performed at the final stage in manufacturing a product. The high quality and fully automated production demand focuses attention on the surface condition of the product, especially the roughness of the machined surface, because of its effect on product appearance, function, and reliability. Surface roughness is quantified by the vertical deviations of actual surface from its ideal form. If these deviations are large, then the surface is rough; if these deviations are small then the surface is smooth

In recent years the challenge is to increase the production rate, decreasing operation cost, and enhancing the quality of production. Among the various factors cutting parameters, cutting speed, feed rate and depth of cut will play a significant role in machining quality. Therefore, suitable selection of these parameters is necessary for optimal machining conditions to enhance production efficiency. Various researchers have performed experimental investigations about the machining operations and evaluated the effect of cutting parameters on the output of the process, But implementation of numeric experimental tests such as hit and trail for finding optimal conditions of the process is time consuming and costly. In order to optimize this problem many researchers have attempted to model the machining processes by various methods such as statistic, intelligent and analytical methods. Zhang et al. have used Taguchi method for surface finish optimization in CNC Turning. The result of experiment indicates that the effects of spindle speed and feed rate on surface finish were larger than depth of cut for machining operation.

Austenitic stainless steels have a high work hardening rate, low thermal conductivity, high corrosion resistance, High strength, high built-up-edge(BUE) tendency, and high deformation hardening. These are the main factors that make their machinability difficult. These factors are responsible for the poor machinability of austenitic stainless steels. Also during cutting they form very strong bond with the cutting tool during cutting. During cutting when chip is broken away, it may bring fragment of tool, particularly when machining with cemented carbide tools. operators encounter problems like poor surface finish and tool failure due to high temperature at tool–work piece interface during machining of AISI 304. In this study, turning tests were carried to determine the optimum machining parameters i.e best cutting speed and feed rate were according to flank wear,Built up edge (BUE), chip form, surface roughness of the machined samples and machine tool power consumption.

Tables 1.1 chemical composition of AISI 304

C	0.05487
Si	0.64
Mn	1.66
Cr	18.2
Ni	9.11
Mo	0.092
Cu	0.14

Ti	0.006
V	0.046
W	0.048
Co	0.040
Nb	0.013
Pb	0.015
Fe	69.7

1.2.2 Natural Roughness

One of the key aspects contributing to natural SR is the existence of a built-up edge. Thus, greater the built up edge, the rougher would be the surface produced, and aspects tending to reduce chip-tool friction and to eradicate the built-up edge would give enhanced surface finish.

1.3. Turning Principle

Turning is a type of metal removal process, which is used to create rotational parts by cutting away unwanted material as shown in figure 1.2. The turning process requires a CNC turning machine or Lathe, Cylindrical work piece and cutting tool.

The work piece is a piece of pre shaped material that is secured to the fixture, which itself is attached to the CNC turning machine and allow to rotate at high speeds. The cutter is typically a single point cutting tool that is also secured in machine. The Cutting tool feed into rotating work piece and cuts away material in the form of small chips to create the desired shape. The success of a manufacturing industry or production line depends greatly on calibrated machine parts manufactured with precision. They are made to accurate and exact measurements. They can also be customized according to the size preferred by the clients.

1.4. Characteristics of CNC Turning

In the manufacturing industries there is a great requirement for flexibility and adaptability. To fulfill this criterion, the computer numerical control systems or CNC was introduced in the metal cutting processes. These processes were provided with automation of the process with high accuracy and repeatabilityThe CNC machined parts or components are manufactured using superior quality of raw material and the latest sophisticated technology in conformity with the set industrial norms. These components are of increasing importance due to the following reasons:

- Resistance to corrosion
- High performance
- Durable and Long service life
- Precise dimension

The CNC machined parts can be used in a variety of industries for varied purposes. These components are suitable turned depending upon the application. They are also machines and anodized to make them a preferred choice among various industries. These components are popularly used as machine spare parts. They can also be customized according to the size preferred by the clients. They are also made available in varied tempers and alloys according to the requirement of the customers and for the different purpose of the industries.

Figure 1.1. CNC Machine

In the recent years there has been an increasing importance of CNC turned components. The reason for this is due to their distinct features.

- Compact Size and Design
- Highly efficient

- Temperature resistant (Meat Probes)
- High corrosion resistance

The success of a manufacturing industry or production line depends greatly on calibrated machine parts manufactured with precision. They are made to accurate and exact measurements. Specialized CNC turning machinery is used to produce these complex parts quickly within a fraction of a second. Their products are in great demand owing to the accurate dimension, robustness and rugged construction. The products are engineers with precision using the best quality components and implementing sophisticated technologies.

1.5. Important Parameters of CNC Turning

In turning the speed and motion of cutting tool is specified through several parameters. These parameters are selected for each operation based upon the work piece material, tool material etc. CNC turning parameters that can affect largely the turning process are:

- **Spindle speed** – The rotational speed of the spindle and the work piece in revolution 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. In order to maintain constant cutting speed, the spindle speed must vary based on diameter of cut.
- **Feed Rate-** The speed of cutting tool movement relative to the work piece as tool makes a cut. The feed rate is measured in mm per minute.
- **Depth of Cut-** The depth of tool along the axis of the work piece as it makes a cut., as in facing operation.

1.6. Tool Material and its Properties

For modern industrial production, in particular mass production, machining is one of the most important shaping and forming processes. The cutting tool which is used for the present work was a carbide tip-CNMG 120408-THM-F. The fundamental properties of carbide tools have great hardness over a wide range of temperature ; are very stiff (Young's modulus is nearly three times that of steel); exhibit no plastic flow (yield point) even on experiencing stresses of the order of 33300 kg/cm^2, have low thermal expansion compared with steel ; relatively high thermal conductivity: and a strong tendency to form pressure weld at low cutting speed, these are weak in tension than in compression. Their high hardness at elevated temperature enable them to be used at much faster cutting speed (3 to 4 m/sec with mild steel) superior hot hardness and wear resistance. These can retain cutting hardness upto 700°C and have high wear resistance. The tool used was cemented carbide insert type with tip radius 0.8mm.

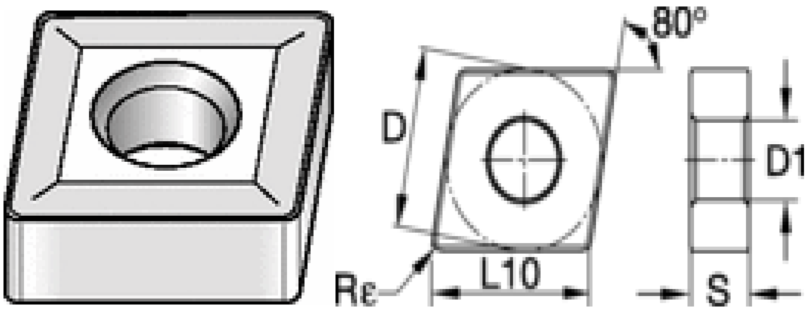

Figure: 1.2 Carbide tool specification[2]

Table 1.2 Carbide Tool Specification

ISO catalog number	**ANSI catalog number**	**Grade**	**D (mm)**	**L10 (mm)**	**S (mm)**	**Rε (mm)**	**D1 (mm)**
CNMG 120408	CNMG432	THM-F	12,70	12,90	4,76	0,8	5,16

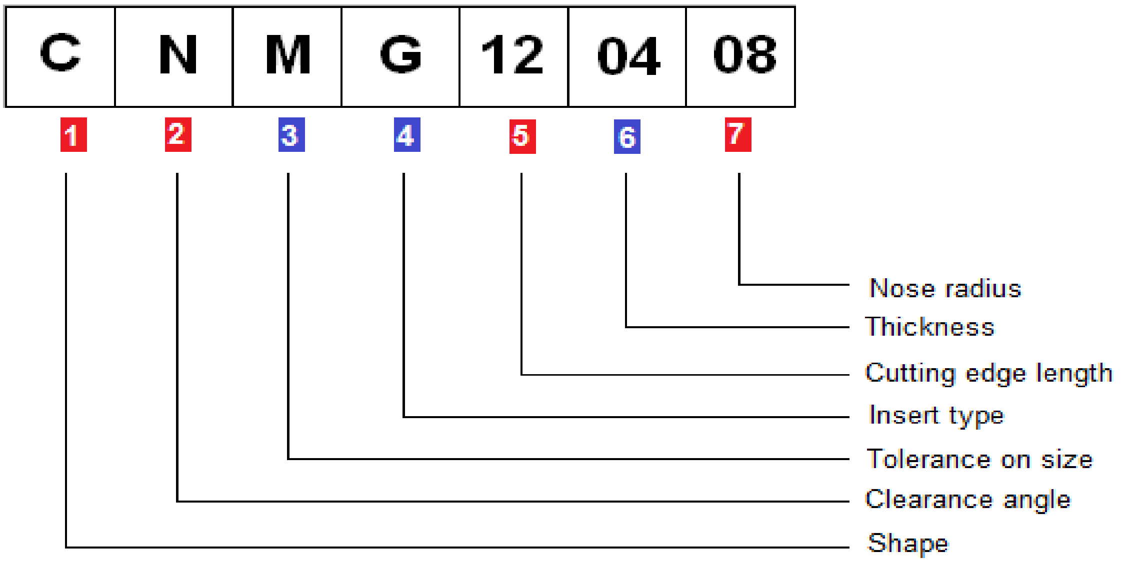

Figure: 1.3 Carbide tool insert-ISO nomenclature[2]

Figure: 1.4 Carbide tool material (CNMG 120408-THM-F)

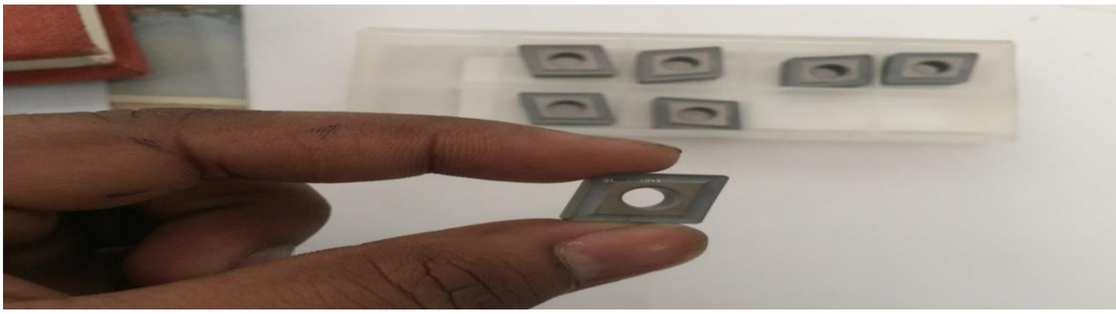

Figure: 1.5 Carbide tool material (CNMG 120408-THM-F)

1.7. Advantages

- Less time consumption and cost for finding optimal parameters of CNC turning.
- Easy to find the most significant parameter, which affect widely the surface roughness and metal removal rate. So easy to predict the parameter which need much attention to control.
- Higher surface finish with high accuracy and minimum variation.
- Increase in metal removal rate up to optimality.
- Decrease in tool wear rate and increase in product quality.

1.8. Experimental Methodology

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analyzed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed. The advantages of design of experiments are as follows:

- Numbers of trials is significantly reduced.
- Important decision variables which control and improve the performance of the product or the process can be identified.
- Optimal setting of the parameters can be found out.
- Qualitative estimation of parameters can be made.
- Experimental error can be estimated.
- Inference regarding the effect of parameters on the characteristics of the process can be made.

1.9. Statement of Problem

Optimization of turning parameter is usually a difficult work where the following aspects are required as knowledge of machining and the specification of machine tool capabilities. The level of parameter is the important part because it will affect the output response of the work piece. In CNC turning operation it is important task to select a good combination of process parameters level for achieving high cutting performance. Generally, this combination is hard to find.

The present work “Optimization of Metal Removal Rate and Surface Roughness in CNC Turning by Taguchi method” has been undertaken keeping into consideration the following problems:

- It has been long recognized that cutting conditions such as spindle speed, feed rate, depth of cut and other machining parameters should be selected to optimize the economics of machining operations as assessed by productivity, total manufacturing cost per component or other suitable criterion.
- High cost of numerically controlled machine tools, compared to their conventional counterparts, has forced us to operate these machines as efficiently as possible in order to obtain the required payback.
- Predicted optimal solutions may not be achieved practically using optimal setting of machining parameters suggested by any optimization technique. So, all the predicted optimal solutions should be verified experimentally using

suggested combination of machining parameters.

1.10. Thesis Layout

Chapter 1 deals with the general introduction, principle, characteristics, tool material, important factors, advantages, and applications of CNC Turning Machine, statement of the problem, and objectives of the present investigation.

Chapter 2 presents the review of the published literature on machining under different conditions, optimization of process parameters, multi-objective optimization of machining parameters used in CNC Turning process. Also, the identified gaps in the literature have been discussed.

Chapter 3 deals with the details of the experimental set-up and the equipment used for measurement of different performance characteristics of the machined parts (metal removal rate and surface roughness) and their evaluation criterion. Also, the levels of the process parameters based on preliminary investigation are finalized in this chapter.

Chapter 4 deals with analysis of result and discussion of result with details of Taguchi experimental design technique and ANOVA (analysis of variance). Also, the data analysis procedure has been described in this chapter. The responses are simultaneously optimized and the optimal levels of the process parameters are determined.

Chapter 5 contains the summary and conclusion of the research conducted in this thesis. Also, at the end of this chapter, some suggestions for future work on the related topics have been enumerated.

1.11. Objective of Present Work

- Determine optimum turning parameter for metal removal rate.
- Determine optimum turning parameter for surface roughness.

Investigation of the working ranges and levels of the CNC Turning process parameters using following approach:

- Experimental determination of the effects of the various process parameters as spindle speed, feed rate and depth of cut on the performance measures as metal removal rate, surface roughness in CNC turning process.
- Optimization of the performance measures using Taguchi method.
- Analysis of variance of the performance measures using ANOVA.
- Validation of the results by conducting confirmation experiments.

CHAPTER 2

LITERATURE REVIEW

2.1. Overview

This chapter discussed about the optimization technique, Taguchi method is review to get complete understanding before applied to study.

In this chapter, some selected research papers have been discussed related CNC Turning Optimization. The studies carried out in these papers are mainly concerned with the CNC Turning parameters as spindle speed, feed rate and depth of cut etc. and how these affect the machining characteristics like Metal Removal Rate and Surface Roughness.

2.2. Research Paper Study

Nithyanandhan T. et al. [1] had investigated the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of process parameters. And the analysis of Variance (ANOVA) is also used to analyze the influence of cutting parameters during machining. In this work, AISI 304 stainless steel work pieces are turned on conventional lathe by using tungsten carbide tool. The results revealed that the feed and nose radius is the most significant process parameters on work piece surface roughness. However, the depth of cut and feed are the significant factors on MRR.

D. Philip Selvaraj et al. [2] had studied the Taguchi optimization method was applied to find the optimal process parameters, which minimizes the surface roughness during the dry turning of AISI 304 Austenitic Stainless Steel. A Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters. ANOVA results shows that feed rate, cutting speed and depth of cut affects the surface roughness by 51.84%, 41.99% and 1.66% respectively. A confirmation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

Samruddhi Rao et al. [3] presented a detailed overview of Taguchi Method in terms of its evolution, concept, steps involved and its interdisciplinary applications. It could be concluded that this method with its perfect amalgamation of statistical and quality control techniques was one of the effective and efficient methods of its kind to highlight the benefits of designing quality into products upstream rather than inspecting out bad products downstream. It offers a quantitative solution to identify design factors to optimize quality and reduce cost. Also the application of this method is not confined to a particular domain but also to other fields like product and service sec-tors. It thus is a powerful method as compared to the other

intuitive and more cumbersome methods encompassing a large number of fields in terms of application.

Krishnakant et al. [4] analyzed that an optimization of turning process by the effects of machining parameters applying Taguchi methods to improve the quality of manufactured goods, and engineering development of designs for studying variation. EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate.

Quazi T Z et al. [5] had made an attempt to review the literature on optimizing machining parameters in turning processes by Taguchi method. The settings of turning parameters were determined by using Taguchi's experimental design method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA) are employed to find the optimal levels and to analyze the effect of the turning parameters.

Atul Kulkarni et al. [6] used Taguchi method to optimize cutting parameters during dry turning of AISI304 austenitic steel with AlTiCrN coated tool.

W. H. Yang et al. [7] had discussed an application of the Taguchi method for optimizing the cutting parameters in turning operations. The Taguchi method provides a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques. It has been shown that tool life and surface roughness can be improved significantly for turning operations.

M. Adinarayana et al. [8] had presented in paper the multi response optimization of turning parameters for Turning on AISI 4340 Alloy Steel. Experiments are designed and conducted based on Taguchi's L27 Orthogonal array design. This paper discusses an investigation into the use of Taguchi parameter Design and Regression analysis to predict and optimize the Surface Roughness, Metal Removal Rate and Power Consumption in turning operations using CVD Cutting Tool. The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning. This paper also remarks the advantages of multi-objective optimization approach over the single-objective one. The useful results have been obtained by this research for other similar type of studies and can be helpful for further research works on the Tool life and Vibration of tools etc.

Vikas B. Magdum et al. [9] Studied for optimization and evaluation of machining parameters for turning on EN8 steel on Lathe machine.This study investigates the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristics. Develop a methodology for optimization of cutting forces and machining parameters.

Sijo M. T. et al. [10] analyzed that for solving machining optimization problems, various conventional techniques had been used so far, but they are not robust and have problems when applied to the turning process, which involves a number of variables and constraints. To overcome the above problems, Taguchi method is used in this work. Since Taguchi method is experimental method it is realistic in nature. According to this study the prime factor affecting surface finish is feed rate.

Elso Kuljanic et al. [11] analyzed that assessment of the machinability rating of an engineering material is a fundamental activity to increase the productivity and decrease the machining cost. It is also necessary to optimize materials selection in design of mechanical parts. However, it is not a simple task to summarize chemical, mechanical and tribological properties in simple statistical parameters and therefore a more reliable solution is to make machining tests. This paper deals with machinability index, short machinability testing, conventional machinability testing, effect of tool life data analysis on tool life equation, ISO standards for tool life testing and computerized machinability data system developed according to the Integrated Machinability Testing Concept.

Kompan Chomsamutr et al. [12] objective of research is to compare the cutting parameters of turning operation the work pieces of medium carbon steel (AISI 1045) by finding the longest tool life by Taguchi methods and Response Surface Methodology: RSM. This research is to test the collecting data by Taguchi method. The analyses of the impact among the factors are the depth of cut, cutting speed and feed rate. This research found that the most suitable response value; and tool life methods give the same suitable values, i.e. feed rate at 0.10 mm/rev, cutting speed at 150 m/min, and depth of cut at 0.5 mm, which is the value of longest tool life at 670.170 min, while the average error is by RSM at the percentage of 0.07 as relative to the testing value.

Sunil Kumar Sharma et al. [13] had analyzed that Taguchi optimization technique pair with grey relational analysis has been adopted for evaluating parametric complex to carry out acceptable surface roughness lower is better, material removal rate higher is better of the AISI 8620 steel during turning on a CNC Lathe Trainer. After identify the optimal process parameters setting for turning operation, ANOVA is also applied for finding the most significant factor during turning operation. In this study it is concluded that the feed rate is the most significant factor for the surface roughness and material removal rate together, as the P-value is less than 0.05. Cutting speed and depth of cut is found to be insignificant from the ANOVA study.

Anand S. Shivade et al. [14] had analyzed that the application of single characteristics optimization approaches for turning processes.These approaches utilized in many fields to optimize the single and multi performance characteristics efficiently. Turning is one of the most basic machining processes in traditional manufacturing process.

Y. Mustafa & T. Ali [15] had conducted experiments on aluminum alloy work piece to analyze geometric tolerance and surface roughness by turning. The effect of the length and diameter of working piece, depth of cut and feed were also investigated. They used Taguchi and ANOVA approach to analyze the data. They found from the experiments: (i) The minimum surface roughness value was 0.831 μm, (ii) The minimum cutting force was 94 N, (iii) The minimum work piece cylindricity error was 0.019 mm.

They also concluded from these number of experiments that : (1)cylindrical error the workpiece length and feed are the most significant factor, (ii) Surface roughness, the feed and work piece diameter are the most significant parameters & (iii) for force the most significant parameters are DOC and feed.

Ali Abdallah et. al. [16] had optimized cutting parameters for the surface roughness in CNC turning machining with aluminum alloy6061 material. They had applied ‘response surface methodology’ on the most effective process parameters, namely, feed, cutting speed, and depth of cut, and optimized considering the surface roughness and material removal rate for turning process. Based on the results of surface roughness it was analyzed that feed rate affects both MRR and surface roughness. The effect of cutting speed in the cutting process is more significant on surface roughness than on MRR. Higher the cutting speed results in better surface roughness and this finding can be explained along with other significant parameters. The depth of cut also influences both MRR and surface roughness in the cutting process

Biswajit Das et. al. [17] had studied surface roughness on turning operation using CNC lathe. The process parameters used in the experiment were cutting speed, depth of cut and feed rate. Other parameters such as tool nose radius, work piece length, work piece diameter, and work piece material were taken as constant. They concluded that, the feed rate is a dominant parameter and feed rate makes dramatic changes in the surface finish of the machined surface.

Dr. M. Naga Phani Sastry et. al. [18] had tried to investigate parameters which are most significant for the material removal rate and surface roughness. They used Response Surface Methodology (RSM) for this study. They applied methodology on most effective process parameters i.e. feed, cutting speed and depth of cut while machining aluminum alloy and resin as the two types of work pieces using HSS cutting tool. They analyzed the data set, using statistical tool DESIGN EXPERT-8 Software and reduce the manipulation. They found following results

- The minimum surface roughness value was 1.18 μm for Aluminium alloy and 2.295 μm for resin.
- The maximum metal removal rate was found to be 1377.83 mm^3/min for Aluminium alloy and 182.899 mm^3/min for resin.

Durai Matinsuresh Babu et. al. [19] had tried to find out the effects of process parameters such as speed, feed and depth of cut on power consumption in high tare CNC machines. They observed during experiments that (1) the feed rate and the depths of cut are greatly influencing the energy consumption in CNC machines. (2) Increasing the cutting speed by 50%, decreases tool life by 80% and operating at lower cutting speed (20-40m/min) tends to cause chattering. Thus, tool life is shortened. Hence the optimum cutting speed is 200-275 m/min in case of CNC turning.

Gaurav Vohra et. al. [20] had optimized the boring parameters for aluminium material on CNC turning centre such as speed, feed rate and depth of cut, to achieve the highest possible material removal rate and at the same time minimum surface roughness by using the Taguchi method. They found that for the material removal rate the speed and depth of cut are the most significant parameters and for surface roughness speed and feed are the most significant parameters.

H. M. Somashekara et. al. [21] used process parameters like speed, feed and depth of cut to optimize the value of Surface Roughness while machining Al 6351-T6 alloy with Uncoated Carbide Inserts. They have used several statistical modeling techniques to generate models including Genetic Algorithm, Response Surface Methodology. They also used Taguchi Technique to optimize the process parameters and ANOVA analysis was also performed to obtain significant factors influencing Surface Roughness. They concluded that

- Speed has a greater influence on the Surface Roughness followed by Feed.
- Depth of Cut had least influence on Surface Roughness.

The error occurred during the validation experiment was less than 2.0 % between equation and actual value

Madhav Murthy et. al. [22] had studied the effect of various cutting parameters on the surface finish of Al 6061 aluminium alloy.L16 orthogonal array was selected for conducting turning experiments on Al6061 T6 using CNC LT-16 turner with carbide tipped tool and the cutting parameters selected were feed, spindle speed, depth of cut and tool nose radius. The L16 array used 4 factors at 2 levels each and the experiments were conducted. The results obtained were analyzed using ANOVA and the regression equation for predicting the surface roughness. They found that the feed is the most significant in influencing the surface roughness while the remaining three factors considered are not significant.

Md. Tayab Ali et. al. [23] had optimized the cutting parameters like spindle speed, feed rate, and depth of cut for minimization of Surface Roughness and maximization of material Removal Rate (MRR) in CNC turning of Aluminum Alloy (AA6063-T6) using carbide insert tool in dry condition. They have taken L9 orthogonal Array (OA) for the study and Minitab- 17 statistical software was used to analyze the data. They found that the most significant parameters for surface roughness are feed rate, spindle speed and least significant factor is depth of cut. For MRR, the depth of cut and the spindle speed is the most significant parameters and least significant factor is feed rate.

Mohan Singh et. al. [24] had presented a fractional factorial experimentation approach to studying the impact of turning parameters on surface roughness on aluminum material. They used regression analysis for evaluation of parameters of surface roughness. They analyzed the results using Excel or MINITAB15. They found that the depth of cut does not impact the surface roughness in the studied range, which could be used to improve productivity. They also found that

- Feeds, nose radius, work material and speeds, the tool point angle has a significant impact on the observed material surface roughness.
- Cutting speed, feed rate, and nose radius have a major impact on surface roughness. Smoother surfaces will be produced when machined with a higher cutting speed, smaller feed rate and nose radius.

The interactions of the cutting speed, nose radius, and feed rate also have a more significant impact on surface roughness than the individuals.

N. Radhika et. al. [25] had focused on the design of a new hybrid composite as well as to analyze the optimum turning conditions to minimize the surface roughness and work piece surface temperature, thereby increasing the productivity. Experiments were conducted based on the Taguchi parameter design by varying the feed (0.1, 0.15 and 0.2 mm/rev), cutting speed (200, 250 and 300 m/min) and depth of cut (0.5, 1.0 and 1.5 mm). They found that there is an increase in the surface roughness of hybrid composites increases feed and depth of cut, but the surface roughness decreases with increase in cutting speed.

N.Prabhakar et. al. [26] had studied the influence of machining parameters on surface roughness and material removal rate is examined by using ANN & ANOVA techniques. The experiments have been conducted on Aluminum alloy AL 6253 using CNC turner with carbide tip tool and experimental results were analyzed by using ANOVA and the regression equation for predicting the surface roughness and MRR. The ANOVA and ANN results revealed that feed rate and depth of cut are the most significant influencing factors on the material removal rate and surface finish.

Narayana B. Doddapattar et. al. [27] had worked to carry out experimental investigations to optimize machinability of commercial Al – 7050 (Aluminium) and to obtain optimum process parameters. They used Taguchi's orthogonal array based on design of experiments for optimization of process parameters of CNC. They concluded that there are several options through which the surface roughness can be obtained that is through cutting speed, feed rate, depth of cut, and nose radius. They observed that MRR in CNC turning process is greatly influenced by depth of cut.

Ranganath M S et. al. [28] had investigated the parameters affecting the surface roughness produced during the turning process for the material aluminium 6061 using CNC lathe. They used Taguchi and ANOVA approach to analyze the experimental results. They found that the feed and speed are the most influential process parameters on surface roughness.

Ravindra Thamma [29] had predicted and developed various models for the optimum turning parameters for required surface roughness for an aluminium 6061 work pieces. He concluded that

- Cutting speed, feed rate, and nose radius have a major impact on surface roughness. Smoother surfaces will be produced when machined with a higher cutting speed, smaller feed rate, and nose radius.
- Depth of cut has a significant impact on surface roughness only in an interaction.
- The interactions of the cutting speed, nose radius, and feed rate also have a more significant impact on surface roughness than the individuals.

Rishu Gupta et. al. [30] worked on findings of an experimental investigation effect of cutting speed, feed rate, depth of cut and nose radius on material removal rate and surface roughness in CNC turning of Alloy 6061 material. The conclusion revealed that the feed rate and nose radius were the most influential factors on the surface roughness and Material Removal Rate (MRR) in CNC turning process which is greatly influenced by depth of cut followed by cutting speed.

S.V. Alagarsamy et. al. [31] had conducted experiment by turn aluminium Alloy 7075 using TNMG 115 100 tungsten carbide insert at three levels (Speed, feed & DOC) of cutting parameters and analyzed by employing Taguchi technique and respond surface methodology. Taguchi method and Response surface methodology were applied for analyzing to get a minimum surface roughness and maximum material removal rate for turning process of Aluminum Alloy 7075 using CNC machine via considering three influencing input parameters- Speed, Feed and Depth of Cut. They found that the input parameter feed has most influencing to the quality characteristics of surface roughness and depth of cut being most affecting parameter for MRR.

Senthil Kumar et. al. [32] had studied to find the optimum machining parameter of CNC turning centre on Al-HMMC for low value of surface roughness and high Material Removal Rate (MRR). Signal to Noise ratio (S/N) and Analysis of Variance (ANOVA) were used to analyze the effect of cutting parameters on surface roughness and MRR. The conclusion revealed that the feed rate and nose radius were the most influential factors on the surface roughness and Material Removal Rate (MRR) in CNC turning process which is greatly influenced by depth of cut followed by cutting speed. The conclusion revealed that the feed rate and nose radius were the most influential factors on the surface roughness and Material Removal Rate (MRR) in CNC turning process which is greatly influenced by depth of cut followed by cutting speed. They found out that the feed rate is the most significant parameter, cutting speed is the second significant parameter and the depth of cut is the third significant parameter on surface roughness and for material removal rate the feed rate is the most significant parameter, cutting speed is the next significant parameter and the depth of cut is the third significant parameter.
Vipindas M P et. al. [33] worked on findings of an experimental investigation of effects of speed, feed and depth of cut on surface roughness during turning of Al 6061 material using Coated carbide inserts. They found that: 1. The lowest surface roughness (Ra) of 0.33 μm was achieved corresponding to: feed: 0.1 mm/rev, Speed: 1000 rpm and depth of cut: 0.4mm. and 2. The most significant parameter in influencing the quality of machined surfaces was feed.

2.3. Conclusions from Literature Review and Recommendation Identified

After a comprehensive study of the existing literature, a number of gaps have been observed in CNC Turning of AISI 304:

- Most of the researchers have investigated influence of a limited number of process parameters on the performance measures of CNC Turning.
- Literature review reveals that the researchers have carried out most of the work on CNC Turning developments, monitoring and control but very limited work has been reported on optimization of process variables.
- The effect of machining parameters on Carbide tool steel has not been fully explored using CNC Turning.

CHAPTER 3

EXPERIMENTAL PROCEDURE

The work piece is a piece of pre shaped material that is secured to the fixture, which itself is attached to the CNC turning machine and allow to rotate at high speeds. The cutter is typically a single point cutting tool that is also secured in machine. The Cutting tool feed into rotating work piece and cuts away material in the form of small chips to create the desired shape.

3.1. Machine and Equipment’s

There are different types of equipment’s which are used in this experimental works are CNC Turning Machine, Surface Roughness Tester and Design Expert Software Minitab 15.

3.1.1. CNC Turning Machine (Turret type)

The turning process requires a CNC turning machine or Lathe, Cylindrical work piece and cutting tool.The work piece is a piece of pre shaped material that is secured to the fixture, which itself is attached to the CNC turning machine and allow to rotate at high speeds.

Figure 3.1 CNC Turning Machine (Type: LL20T3)

Table 3.1 Technical Specification of CNC

Model	**Turn master-3S**
Capacity	
Swing over bed	510mm
Swing over carriage	340mm
Admit between centres	420mm
Maximum Turning Length	310mm
Interference free Turning dia	265mm
Maximum Turning Diameter	320mm
Chuck size	210 (8”)mm
Spindle	
Spindle Nose	A2-6
Spindle Inside Taper	MT-7
Hole through Spindle	61mm
Maximum Bar Capacity	51mm
Spindle speed range	3500rpm
Maximum Torque in Spindle	140Nm
Turret	
Number of stations	8
Tool shank size	25x25mm
Maximum Boring bar diameter	40mm
Indexing	Bi-directional

Indexing time (per station)	0.9sec
General	
Machine size (Length x Breadth x Height)	2065x1925x1680
Weight (Approx.)	3500kg
Floor Space required	4.0m^2
Power Supply	
Voltage	AC, 415 ±10% V, 3□□
Frequency	50 ± 1 Hz
Power	22.2Kva
Accuracy	
Positioning of slides - X Axis	0.005mm
Positioning of slides - Z Axis	0.010mm
Repeatability : X-Axis / A Axis	± 0.002 / ±0.003mm
CNC System	Fanuc 0i- mateTD

3.1.2. Surface Roughness Tester

Brand: Taylor Hobson, Model: Surtronic 3+
Surface roughness of the machined work pieces was measured using this machine. The Surtronic 3+ is a movable, self-contained for the measurement of surface texture and is appropriate for use in both the workshop and laboratory. Parameters accessible for surface texture evaluation are: R_a, R_q, R_z (DIN), R_y.
The parameters evaluations and other functions of the instrument are microprocessor based. The measurement results are displaced on an LCD screen and can be output to a voluntary printer or another computer for further results.

The instrument is normally powered by an alkaline non-rechargeable battery. If preferred, a Ni-Cad rechargeable battery can be used

Figure 3.2 Roughness Tester

3.1.3 Display-Transverse Unit

The top panel of the display-traverse unit carries a membrane type control panel and a liquid crystal display. The unit houses the electronics for controlling the measurement sequence, calculating the measurement data and outputting the results to the display, or to the RS232 port for use with a printer (when included) or to a computer for further analysis.

The unit also comprises a drive motor which traverses the pickup across the surface to be measured. The measuring stroke always starts from the extreme outward positions. At the conclusion of the measurement the pickup returns to this position prepared for the next measurement. The traverse length is determined from selections of cut-off (Lc) or length (Ln).

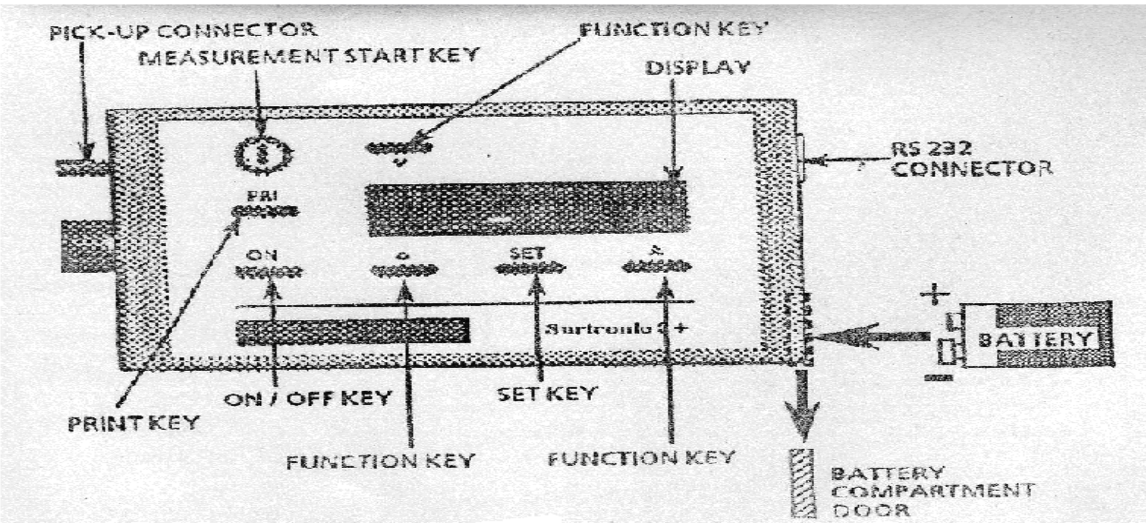

Figure 3.3 Display Transverse Unit (Referred from Instrument Manual)

3.1.4 Pick-Up Mounting Components

The pick-up is fastened to the drive shaft by the following means.

3.1.5 Mounting Bracket

This is fastened to the drive shaft by means of a knurled knob. Although normally used upright, it can be turned to angle the pick-up or to take it off the centre line. It can also be mounted sideways on the drive shaft, when the right-angle pick-up is in use.

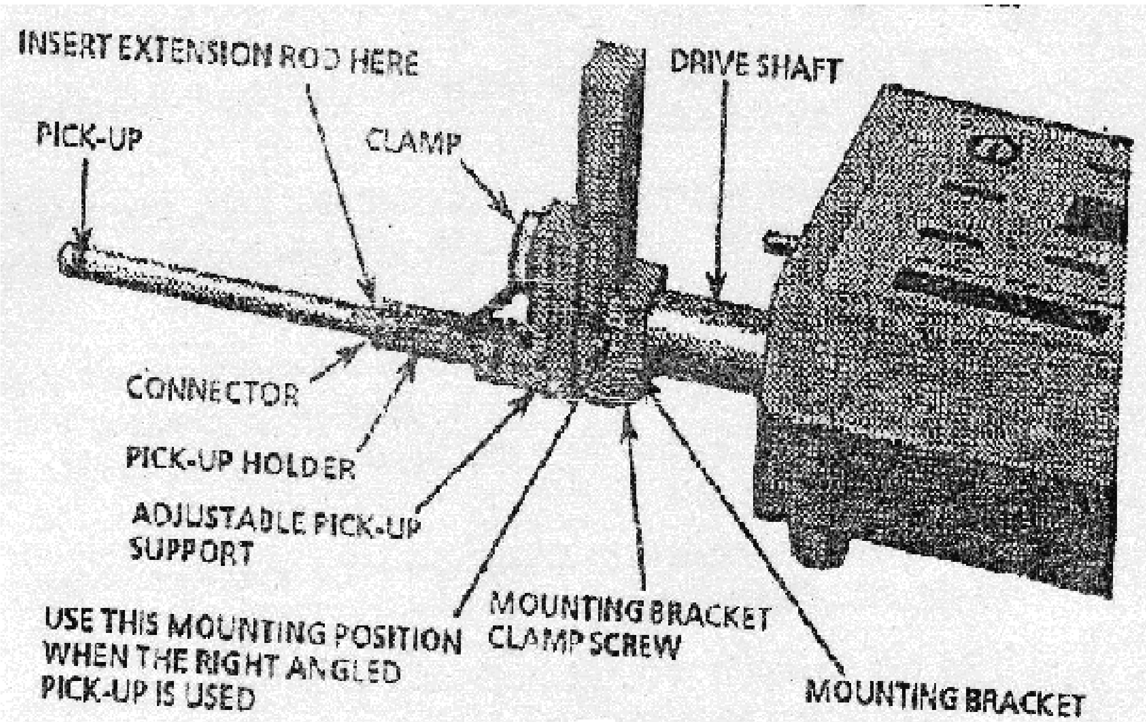

Figure: 3.4 Mounting Bracket (Referred from Instrument Manual)

3.1.6 Adjustable Support

This can be clamped at any positions on the slide of the mounting bracket to provide pick-up height adjustment.

3.1.7 Pick-up Holder

This fits into the crutch of the pick-up support and is held in place by a spring plunger.

3.1.8 Connector

The connector of the pick-up lead is screwed into the end of pick-up and is then inserted into the end of the pick-up holder, with the lead coming out through the slot in the holder. It is advisable to connect the lead to the display-traverse unit first and then to the pick-up. When the extension rod is used, the short pick-up is not required and the end of the rod itself is inserted into the holder.

3.1.9 DIP switch settings

The instrument default settings, when powering up with a new battery, are set via DIP switches housed inside the display-traverse unit. The selections can be altered by menu/pushbuttons operations. The DIP switches are accessed by unscrewing the three feet from the base of the display-traverse unit, then removing the screws which were partly covered by the feet.

3.1.9 Pick-up

The pickup is a variable reluctance type transducer which is supported on the surface to be measured by a skid, a curved support projecting from the underside of the pickup in the vicinity of the stylus. As the pickup traverses across the surface, movements of the stylus relative to the skid are detected and are converted into a proportional electrical signal. The radius of curvature of the skid is much greater than the roughness spacing. This enables it to ride across the surface almost unaffected by the roughness, and provides a datum representing the general form of the surface. Even so, where the waviness is widely spaced it will be necessary to use the pickup with shoe, in conjunction with the 2.5mm (0.1 in) cut-off.

Table 3.2 Surtronic 3+ Specifications

Battery	Alkaline: Minimum 600 Measurements of 4mm Measurements Lengths. Ni-Cad: Minimum 200 Measurement of 4mm Length Size: 6 LR 61 (USA/Japan), Fixed Battery External Charger (Ni-Cad Only) 110/240V, 50/60 Hz
Traverse Unit	Traverse Speed: 1mm/Sec
Measurement	Metric/Inch Preset by DIP-Switch
Cut-Off Values	0.25mm, 0.8mm, and 2.50mm
Traverse Length	1, 3, 5, 10, Or 25.4 + 0.2mm At 0.8mm Cut-Off.
Display	LCD-Matrix. 2lines * 16 Characters
Keyboard	Membrane Switch Panel Tactile
Filters	Digital Gauss Filters or 2CR Filter (ISO) Selectable By DIP-switch.
Parameters	Ra, Rq, Rz (DIN), Ry and Sm.
Calculations Time	Less Than Reversal Time Or 2 Sec Which Ever Is The Longer.

3.1.10. Design Expert Software Minitab 15

This software was used for planning experimental design matrix and analyzing all the responses according to statistical method.Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. MINITAB software of ANOVA module was employed to investigate effect of process parameters cutting speed, Depth of Cut and Feed rate

3.2. Work piece Material

Work piece was inserted in the Chuck. The turning was carried out for 9 different work pieces.

3.2.1. Work piece Description

- Work piece material : AISI 304 Austenitic SS
- Total no. of specimen : 25
- Shape : Round
- Length : 200mm
- Diameter : 38mm

Figure 3.5 AISI 304 Specimen

Figure 3.6 Machined Specimens

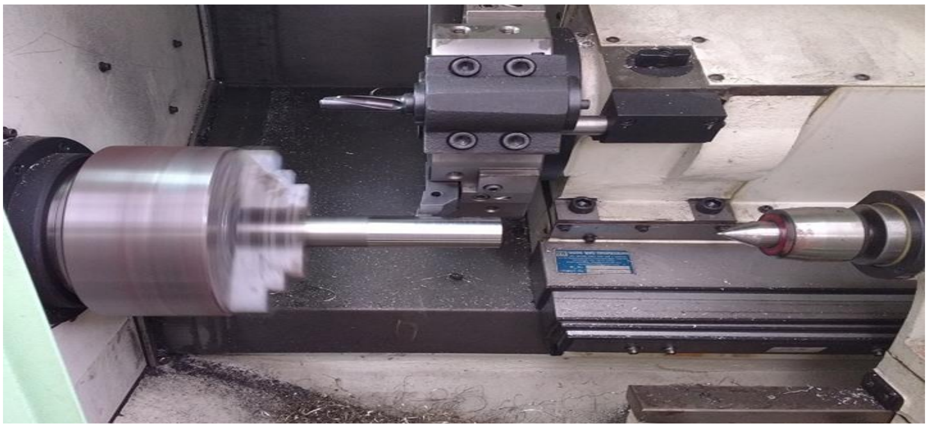

Figure 3.7 CNC Turned Specimen

3.3. Response Parameter

The response parameters include:

- Material removal rate (MRR)
- Surface Roughness (Ra)

3.3.1. Metal Removal Rate (MRR) Measurement

The Metal removal rate (MRR) of the work piece was measured by compared the volume of work piece before and after machining against the machining time that was achieved. After completion of each machining process measurement, the work piece was blown by compressed air using air gun to ensure for blowing out the debris. The following equation is used to determine the MRR value. [24]

$$MRR = fdv$$

$$v = \pi DN$$

Where:

MRR = material removal rate(mm^3/s)

f = feed(mm/rev)

d= Depth of cut (mm)

v = cutting velocity(mm/s)

D= Diameter of work piece before machining (mm)

CHAPTER 4

METHODOLOGY

4.1. Taguchi Philosophy

Taguchi Method was proposed by Dr. G. Taguchi in the year 1950. This method explores the concept of quadratic quality loss function and uses a statistical measure of performance called signal-to-noise (S/N) ratio. In Taguchi method, the process parameters are divided into two groups such as control factors and noise factors. The control factors are the controllable parameters which affect the process significantly whereas noise factors are the variables that affect the process and are either uncontrollable or more expensive to control. Signal represents the effect on the average response while the noise is a measure of the influence on the deviation from the average response. The signal-to-noise (S/N) ratio is the ratio of the mean (Signal) to the standard deviation (Noise), which indicates the scattering around a target value. This ratio helps to identify the optimum level of process parameters. The combination of parameters with the highest signal-to-noise (S/N) ratio will be the optimum setting of process parameters. A high signal-to-noise (S/N) ratio is desirable as the signal level is much higher than the random noise level that leads to best performance. The calculation of signal-to-noise (S/N) ratio depends on the quality characteristics of the product or process to be optimized. The equation for calculating signal-to-noise (S/N) ratios for "larger is better" (HB), "smaller is better".

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In robust parameter design, the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. After we determine which factors affect variation, we can try to find settings for controllable factors that will either reduce the variation, make the product insensitive to changes in uncontrollable (noise) factors, or both.

A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used. Engineering knowledge should guide the selection of factors and responses. When interactions among control factors are likely or not well understood, we should choose a design that is capable of estimating those interactions. Minitab can help us to select a Taguchi design that does not confound interactions of interest with each other or with main effects. Noise factors for the outer array should also be carefully selected and may require preliminary experimentation. The noise levels selected should reflect the range of conditions under which the response variable should remain robust. Robust parameter design uses Taguchi designs (orthogonal arrays), which allow us to analyze many factors with few runs. Taguchi designs are balanced, that is, no factor is weighted more or less in an experiment, thus allowing factors to be analyzed independently of each other. Minitab provides both static and dynamic response experiments.

In a static response experiment, the quality characteristic of interest has a fixed level. In a dynamic response experiment, the quality characteristic operates over a range of values and the goal is to improve the relationship between an input signal and an output response. An example of a dynamic response experiment is an automotive acceleration experiment where the input signal is the amount of pressure on the gas pedal and the output response is vehicle speed. We can create a dynamic response experiment by adding a signal factor to a design see Creating a dynamic response experiment. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. Minitab calculates response tables, linear model results, and generates main effects and interaction plots .Use the results and plots to determine what factors and interactions are important and evaluate how they affect responses. To get a complete understanding of factor effects it is advisable to evaluate signal-to-noise (S/N) ratios, means (static design), slopes (dynamic design), and standard deviations [32].

4.2. Taguchi Design Parameters and Levels

The Taguchi method involves reducing the variation in a process through robust design of experiments. Taguchi's comprehensive system of quality engineering is one of the great engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production and marketplace. Shop-floor techniques provide cost-based, real time methods for monitoring and maintaining quality in production. The farther upstream a quality method is applied, the greater leverages it produces on the improvement, and the more it reduces the cost and time. Quality is the best achieved by minimizing the deviations from the target. The product or process should be so designed that it is immune to uncontrollable environmental variables. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. After conducting the experiments with different settings of inputs factors i.e. spindle speed, feed and depth of cut, the values of output variables surface roughness and materials removal rate were recorded and plotted as per Taguchi design of experiments methodology. The output characteristics surface finish and material removal rate will be analyzed by Minitab software.

In this experiment, the controllable factors are cutting speed (A), feed rate (B), and depth of cut (C), which are selected because they can potentially affect surface roughness performance and material removal rate in Turning operations. Since these factors are controllable in the machining process, they are considered as controllable factors in the experiment. Table listed all the Taguchi design parameters and levels. [32]

For **smaller the Better**

$$\frac{\boldsymbol{S}}{\boldsymbol{N}}\boldsymbol{smaller} = -\mathbf{10}\log_{10}\left[\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{i=1}^{n}\boldsymbol{Y}_i^2\right]$$

For **Larger the Better**

$$\frac{\boldsymbol{S}}{\boldsymbol{N}}\boldsymbol{larger} = -\mathbf{10}\log_{10}\left[\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{i=1}^{n}\frac{\mathbf{1}}{\boldsymbol{Y}_i^2}\right]$$

Where, y_i = experimental value in the i^{th} test. [24]
n = number of replications.
Taguchi method is used to improve the quality of products and processes. Improved quality results when high performance levels are consistently obtained. The highest possible performance is obtained by determining the optimum combination of design factors. Performance consistency is obtained by making the product/process insensitive to the influence of the uncontrollable factors. [24], [26]
The signal-to-noise (S/N) ratio for each level of process parameters are computed. The optimum setting of the process parameters contributes the minimization of the effect of noise. It means that the level of process parameters with the highest signal-to-noise (S/N) ratio corresponds to the optimum level of process parameters.

Table 4.1 Process Parameters and Their Levels

Symbol	**Cutting Parameters**	**Units**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
A	**Speed**	m min^{-1}	71.628	95.504	119.380	143.256	167.132
B	**Feed**	mm rev^{-1}	0.1	0.12	0.14	0.16	0.18
C	**Depth Of Cut**	Mm	0.1	0.15	0.2	0.25	0.3

After deciding parameters and levels as shown above orthogonal array L25 decided as per degree of freedom of each factor and Degree of Freedom(dof) of interaction among the parameters. Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per literature review.

4.3. Orthogonal Array

A Taguchi design, or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

In robust parameter design, we first choose control factors and their levels and choose an orthogonal array appropriate for these control factors. The control factors comprise the inner array. At the same time, we determine a set of noise factors, along with an experimental design for this set of factors.

The noise factors comprise the outer array. The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factors settings for that run of the control factors in the inner array .Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run; the cell values indicate the factor settings for the run. In L25 array 25 rows represent the 25 experiment to be conducted with 3columns at, 5 levels of the corresponding factors. This techniques enable designers to determine simultaneously the individuals and interactive effects of many factors that could affect the output results in any design. There are three input parameters and five level.Each column in the orthogonal array represents a specific factor with two or more levels. The layout of the L_{25} orthogonal array (OA) is shown table. Each run will have three values collected for surface finish. Therefore, a total of (5**3) =25 data values were collected for surface finish and each run will have two data values collected for the material removal rate, therefore a total of (5**3=25) data values for Material Removal Rate(MRR), which are conducted for analysis in the experiment.

Table 4.2 L25 Orthogonal array by Minitab15 software

S.No.	Depth of Cut 'd' Mm	Speed 'S' Rpm	Feed 'f' mm/rev
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	1	5	5
6	2	1	2
7	2	2	3
8	2	3	4
9	2	4	5
10	2	5	1
11	3	1	3
12	3	2	4
13	3	3	5
14	3	4	1
15	3	5	2
16	4	1	4
17	4	2	5
18	4	3	1
19	4	4	2
20	4	5	3
21	5	1	5
22	5	2	1
23	5	3	2
24	5	4	3
25	5	5	4

Table 4.3 Designed L25 Orthogonal array with process parameters

S.No.	Diameter 'D' mm	Speed 'S' Rpm	m/min	Depth of Cut 'd' mm	Feed 'f' mm/rev	MRR(mm^3/min)
1	38	600	71.628	0.1	0.1	716.28
2	38	800	95.504	0.1	0.12	1146.048
3	38	1000	119.380	0.1	0.14	1671.32
4	38	1200	143.25	0.1	0.16	2292.00
5	38	1400	167.132	0.1	0.18	3008.376
6	38	600	71.628	0.15	0.12	1289.304
7	38	800	95.504	0.15	0.14	2205.584
8	38	1000	119.380	0.15	0.16	2865.12
9	38	1200	143.25	0.15	0.18	3867.75
10	38	1400	167.132	0.15	0.1	2506.98
11	38	600	71.628	0.2	0.14	2005.584
12	38	800	95.504	0.2	0.16	3056.128
13	38	1000	119.380	0.2	0.18	4297.68
14	38	1200	143.25	0.2	0.1	2865.00
15	38	1400	167.132	0.2	0.12	4011.12
16	38	600	71.628	0.25	0.16	2865.12
17	38	800	95.504	0.25	0.18	4297.68
18	38	1000	119.380	0.25	0.1	2984.5

19	38	1200	143.25	0.25	0.12	4297.5
20	38	1400	167.132	0.25	0.14	5849.62
21	38	600	71.628	0.3	0.18	3867.912
22	38	800	95.504	0.3	0.1	2865.12
23	38	1000	119.380	0.3	0.12	4297.68
24	38	1200	143.25	0.3	0.14	6016.50
25	38	1400	167.132	0.3	0.16	8022.336

4.4. Part Program

For Specimen

```
O0123;
T0701 ;
G21 G98
G00  X 38.0  Z 2.0;
M03  S600 F140;
G1 X38.0  Z -100.0;
G00 X 40.0 Z 2.0
M05;
M30;
%
```

4.5. ANOVA (Variance Analysis)

Statistical analysis of variance (ANOVA) is performed to identify the design factors that are statistically significant. The optimal combination of the design factors can be predicted based on the result of this analysis. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. All the experimental results obtained are formulated into single indexes and then analyzed to observe the influence of the factors and determine the best design condition. [23]

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate and surface roughness. Based on the ANOVA, the relative importance of the machining parameters with respect to material removal rate and surface roughness is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data:

1. Within treatment variability
2. Observation to observation variability

So analysis of variance (ANOVA) helps us to compare variabilities within experimental data. In my thesis analysis of variance (ANOVA) table is made with help of MINITAB 15 software. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the mean squared error of Y about its target T. The initial techniques of the analysis of variance were developed by the statistician and geneticist R. A. Fisher in the 1920s and 1930s, and are sometimes known as Fisher's analysis of variance (ANOVA) or Fisher's analysis of variance, due to the use of Fisher's *F*-distribution as part of the test of statistical significance.

4.5.1 Various formulas for analysis of variance (ANOVA):

Degrees of freedom (DF)

Degree of freedom indicates the number of independent elements in the sum of squares. The degrees of freedom for each component of the model are:

DF (Factor) = r-1

DF (Error) = n_t– r

Total = n_t– 1

Where

n_t = the total number of observations

and r = the number of factor levels.

Sum of squares (SS)

The sum of squares (SS Total) is the total variation in the data. SS (Factor) is the deviation of the estimated factor level mean around the overall mean. It is also known as the sum of squares between treatments. SS Error is the deviation of an observation from its corresponding factor level mean. It is also known as error within treatments. The calculations are:

$$\mathbf{SS(Factor) = S\ n_i\ (y_i - y_m)^2}$$

$$\mathbf{SS(Error) = S_i\ S_j\ (y_{i\,j} - y_i)^2}$$

$$\mathbf{SS(Total) = S_i\ S_j\ (y_{i\,j} - y_{mi})^2}$$

Where

y_i = mean of the observations at the i^{th} factor level,

y_m = mean of all observations

y_{ij}= value of the j^{th} observation at the i^{th} factor level.

Pure sum of square

SS' (Factor) = SS (Factor) – DF (Factor) * MS (Error)

Mean square (MS)

The calculations for the mean square for the factor and error are:

MS (Factor) = SS (Factor)/ DF (Factor)

MS (Error) = SS (Error)/ DF (Error)

4.6. Experiment Procedure

4.6.1. Measurement for Material Removal Rate (MRR)

Here the desirable objective is to optimize the response variables Measurement for Material Removal Rate (MRR).

A. Calculation of Signal to Noise (S/N) Ratio:

Here the desirable objective is to optimize the response variables Measurement for Material Removal Rate (MRR). Hence Larger-the-better types Signal to Noise (S/N) ratio was applied for transforming the raw data for Measurement for Materiall Removal Rate (MRR) as larger values of Materiall Removal Rate (MRR) as desirable. To find out the Signal to Noise (S/N) ratio of Measurement for Materiall

Removal Rate (MRR) for difference surface roughness values (L25 array). The values of Signal to Noise (S/N) ratio and mean, the following steps are adopted for calculating it:

B. Steps for finding Effect of input factor on Material Removal Rate (larger the better)

For Material Removal Rate (MRR) larger the better means the mean of Material Removal Rate (MRR) should be small for optimum surface finish and S/N ratio should always high for less variation.

Step1.To make response table for Signal to Noise (S/N) ratio (MRR)

- It is done by taking mean of Signal to Noise (S/N) ratio of Material Removal Rate (MRR) for Different levels (Level 1,2,3,4 and 5) of various parameters such as cutting speed, feed rate and depth of cut respectively.
- Find out Delta for Different parameters:

[Delta = { (S/N mean) max - (S/N mean) min }]

- To find rank of respected Parameter, give higher rank to the parameter which have larger delta.
- The parameter with larger delta among all, significantly affect the Material Removal Rate (MRR) of AISI 304 SS, which needed more attention to control among other parameters.

Step2. To make response table for Mean (MRR)

- It is done by taking mean of Material Removal Rate (MRR) for Different levels of various parameters such as cutting speed, feed rate and depth of cut respectively.
- Find out Delta for Different parameters:

[Delta = { (S/N mean) max - (S/N mean) min }]

- To find rank of respected Parameter, give higher rank to the parameter which have larger delta.
- The parameter with larger delta among all, significantly affect the (MRR) of AISI 304 SS, which needed more attention to control among other parameters.

Step3. Analysis of variance with analysis of variance (ANOVA)

ANOVA Table for:

a. S/N Ratio

b. Mean Ra

Step4. Determination of the Optimum Value of Input Parameters for Material Removal Rate (MRR),

4.6.2. Measurement for surface Roughness (Ra)

Here the desirable objective is to optimize the response variables R_a. Hence smaller-the-better types S/N ratio was applied for transforming the raw data for surface roughness as smaller values of R_a as desirable.

A. Calculation of Signal to Noise (S/N) Ratio:

The S/N ratio is obtained using Taguchi's methodology. Here, the term 'signal' represents the desirable value (Mean) and the 'noise' represents the undesirable value (standard deviation). Thus, the Signal to Noise (S/N) ratio represents the amount of variation presents in the performance characteristic. Here the desirable objective is to optimize the response variables R_a. Hence smaller-the-better types S/N ratio was applied for transforming the raw data for surface roughness as smaller values of R_a as desirable. To find out the Signal to Noise (S/N) ratio of surface roughness for difference surface roughness values (L25 array.) The values of Signal to Noise (S/N) ratio and mean, the following steps are adopted for calculating it:

B. Steps for finding Effect of input factor on surface roughness Ra (smaller the better)

For surface roughness smaller the better means the mean of surface roughness should be small for optimum surface finish and Signal to Noise (S/N) ratio should always high for less variation.

Step1.To make response table for Signal to Noise (S/N) ratio (Ra)

- It is done by taking mean of Signal to Noise (S/N) ratio of Ra for Different levels (Level 1,2,3,4 and 5) of various parameters such as cutting speed, feed rate and depth of cut respectively.
- Find out Delta for Different parameters:

[Delta = {(S/N mean) max - (S/N mean) min}]

- To find rank of respected Parameter, give high rank to the parameter which have larger delta.
- The parameter with larger delta among all significantly affects the surface

roughness of AISI 304, which needed more attention to control among other parameters.

Step2. To make response table for Mean surface roughness (Ra)

- It is done by taking mean of surface roughness (Ra) for Different levels of various parameters such as cutting speed, feed rate and depth of cut respectively.
- Find out Delta for Different parameters:

[Delta = { (S/N mean) max - (S/N mean) min }]

- To find rank of respected Parameter, give High rank to the parameter which have larger delta.
- The parameter with larger delta among all significantly affects the surface roughness of AISI 304, which needed more attention to control among other parameters.

Step3. Analysis of variance with Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to determine which cutting parameters significantly affect the surface roughness (R_a). A better feel for the relative effect of the different factors can be obtained by the decomposition of the variance, which is commonly known as analysis of variance (ANOVA). Table Show the results of analysis of variance (ANOVA) analysis of Signal to noise ratio data for means. The most significant input factor is feed rate for surface roughness. The purpose in conducting analysis of variance (ANOVA) is to determine the relative magnitude of each factor on the objective function and to estimate the error variance. In Robust Design, analysis of variance (ANOVA) also used to choose from among many alternatives the most appropriate quality characteristics and Signal to Noise (S/N) ratio for a specific problem. Analysis of Variance (ANOVA) used to investigate which machining parameters affected the observed values significantly. In this test the parameter or the combination of parameter which have P value less than 0.05, those effects significantly

ANOVA Table for:

a. S/N Ratio

b. Mean Ra

Step4. Determination of the Optimum Value of Input Parameters for surface roughness (R_a)

CHAPTER 5

RESULTS AND DISCUSSION

After the experimental results have been obtained, analysis of the results was carried out analytically as well as graphically.

5.1. Layout of the L_{25} Orthogonal Array(OA) with measured Material Removal Rate (MRR)

Each run will have three values collected for surface finish. Therefore, a total of (5**3) =25 data values were collected for surface finish and each run will have two data values collected for the material removal rate, therefore a total of (5**3=25) data values for MRR, which are conducted for analysis in the experiment.

Table 5.1 L25 OA with measured Metal Removal Rate

Exp Run	Spindle Speed (rpm)	Feed Rate(mm/rev)	Depth of Cut(mm)	MRR (mm^3/min)
1	600	0.1	0.1	716.28
2	800	0.12	0.1	1146.048
3	1000	0.14	0.1	1671.32
4	1200	0.16	0.1	2292.00
5	1400	0.18	0.1	3008.376
6	600	0.12	0.15	1289.304
7	800	0.14	0.15	2205.584
8	1000	0.16	0.15	2865.12
9	1200	0.18	0.15	3867.75
10	1400	0.1	0.15	2506.98
11	600	0.14	0.2	2005.584
12	800	0.16	0.2	3056.128

13	1000	0.18	0.2	4297.68
14	1200	0.1	0.2	2865.00
15	1400	0.12	0.2	4011.12
16	600	0.16	0.25	2865.12
17	800	0.18	0.25	4297.68
18	1000	0.1	0.25	2984.5
19	1200	0.12	0.25	4297.5
20	1400	0.14	0.25	5849.62
21	600	0.18	0.3	3867.912
22	800	0.1	0.3	2865.12
23	1000	0.12	0.3	4297.68
24	1200	0.14	0.3	6016.50
25	1400	0.16	0.3	8022.336

After the experimental results have been obtained, analysis of the results was carried out analytically as well as graphically. Graphical analysis is done by MINITAB, shows interactions of all parameters. Then ANOVA of the experimental data has been done to calculate the contribution of each factor in each response. Then we calculated S/N ratio for Material Removal Rate (MRR) and surface roughness of specimens.

Then we obtain optimal conditions has been calculated for Material Removal Rate (MRR) and surface roughness of specimen. The following table shows readings of Material Removal Rate (MRR) and surface roughness at each experiment, it also shows S/N ratio for Material Removal Rate (MRR) and surface roughness

5.2. Discussion and Analysis of MRR by Minitab15 Software:

Larger-the-better types Signal to Noise(S/N) ratio was applied for transforming the raw data for as larger values of MRR as desirable.

5.2.1. Calculation of S/N Ratio for MRR

The S/N ratio is obtained using Taguchi's methodology. Here, the term 'signal' represents the desirable value (Mean) and the 'noise' represents the undesirable value (standard deviation). Thus, the Signal to Noise (S/N) ratio represents the amount of variation presents in the performance characteristic. Here, the term 'signal' represents the desirable value (Mean) and the 'noise' represents the undesirable value (standard deviation). Here the desirable objective is to optimize the response variables MRR. Hence larger-the-better types Signal to Noise(S/N) ratio was applied for transforming the raw data for as larger values of MRR as desirable. The values of Signal to Noise (S/N) ratio and mean corresponding to different experiment runs have been tabulated in Table 5.2.

Table 5.2 Taguchi Orthogonal Array Design for S/N Ratio for MRR

Exp Run	Spindle Speed (rpm)	Feed Rate(mm/rev)	Depth of Cut(mm)	MRR (mm^3/min)	S/N Ratio
1	600	0.1	0.1	716.28	57.1017
2	800	0.12	0.1	1146.048	61.1841
3	1000	0.14	0.1	1671.32	64.4612
4	1200	0.16	0.1	2292.00	67.2043
5	1400	0.18	0.1	3008.376	69.5666
6	600	0.12	0.15	1289.304	62.2071
7	800	0.14	0.15	2205.584	66.8705
8	1000	0.16	0.15	2865.12	69.1429
9	1200	0.18	0.15	3867.75	71.7492
10	1400	0.1	0.15	2506.98	67.983
11	600	0.14	0.2	2005.584	66.0448
12	800	0.16	0.2	3056.128	69.7034
13	1000	0.18	0.2	4297.68	72.6647
14	1200	0.1	0.2	2865.00	69.1425
15	1400	0.12	0.2	4011.12	72.0653

16	600	0.16	0.25	2865.12	69.1429
17	800	0.18	0.25	4297.68	72.6647
18	1000	0.1	0.25	2984.5	69.4974
19	1200	0.12	0.25	4297.5	72.6643
20	1400	0.14	0.25	5849.62	75.3426
21	600	0.18	0.3	3867.912	71.7495
22	800	0.1	0.3	2865.12	69.1429
23	1000	0.12	0.3	4297.68	72.6647
24	1200	0.14	0.3	6016.50	75.5869
25	1400	0.16	0.3	8022.336	78.086

5.2.2. Effect of input factor on Material Removal Rate(MRR)

Here the desirable objective is to optimize the response variables MRR. Hence larger-the-better types Signal to Noise(S/N) ratio was applied for transforming the raw data for as larger values of MRR as desirable.

Table 5.4 Response Table for Means (MRR)

Level	Depth of Cut(mm)	Cutting Speed (rpm)	Feed Rate(mm/rev)
1	1767	2149	2388
2	2547	2714	3008
3	3247	3223	3550
4	4059	3868	3820
5	5014	4680	3868
Delta	3247	2531	1480
Rank	1	2	3

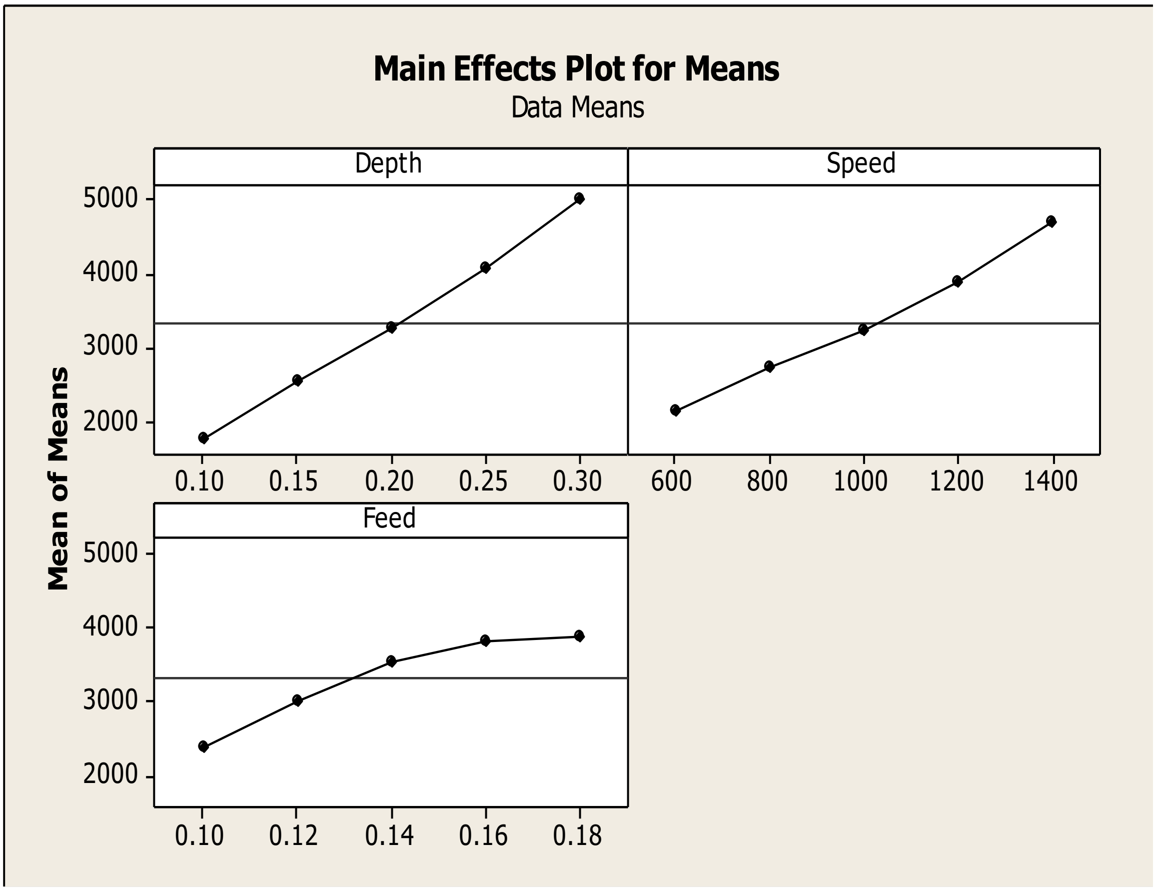

Figure 5.1 Main Effect Plot for Means (MRR)

Table 5.3 Response Table for S/N Ratio- Larger is better (MRR)

Level	**Depth of Cut(mm)**	**Cutting Speed (rpm)**	**Feed(mm/rev)**
1	63.90	65.25	66.57
2	67.59	67.91	68.16
3	69.92	69.69	69.66
4	71.86	71.27	70.66
5	73.45	72.61	71.68
Delta	9.54	7.36	5.11
Rank	1	2	3

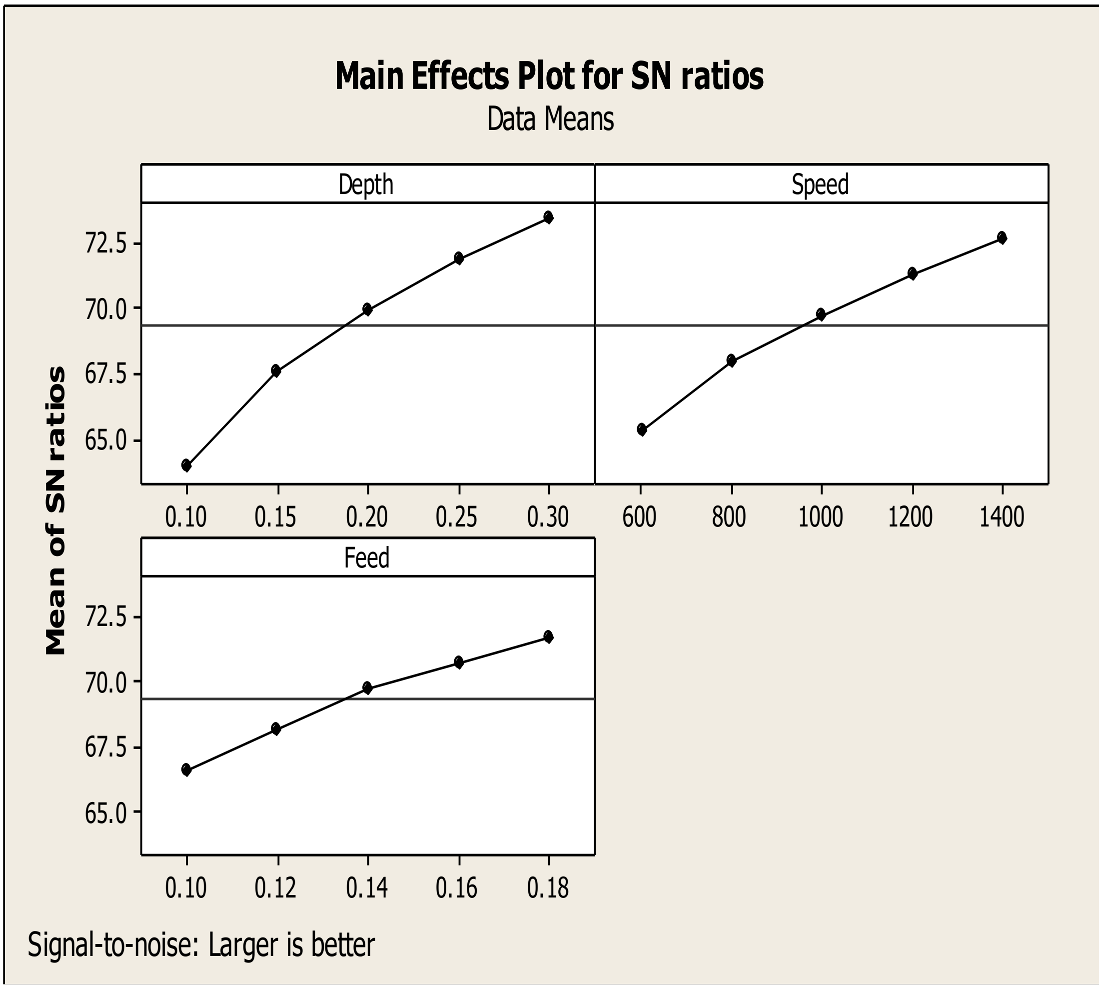

Figure 5.2 Main Effect Plot for S/N Ratio (MRR)

5.2.3. Analysis of Variance Using Adjusted Sum of Squares(SS) for tests

The purpose of the analysis of variance (ANOVA) is to determine which cutting parameters significantly affect the metal removal rate (MRR). A better feel for the relative effect of the different factors can be obtained by the decomposition of the variance, which is commonly known as analysis of variance (ANOVA).

Table Show the results of ANOVA analysis of Signal to noise ratio data for means. The most significant input factor is feed rate for metal removal rate. The purpose in conducting ANOVA is to determine the relative magnitude of each factor on the objective function and to estimate the error variance. In Robust Design, ANOVA also used to choose from among many alternatives the most appropriate quality characteristics and S/N ratio for a specific problem. ANOVA used to investigate which machining parameters affected the observed values significantly. In the present investigation, ANOVA applied to analyze the experimental data. [22] In this experiment the percentage contribution of Depth of Cut is Maximum. The most Significant factor input is Depth of Cut and after that Speed for metal removal rate.

ANOVA Table (Values are Obtained by Software Minitab) for:

a. S/N Ratio.
b. Mean MRR.

Since as already stated ANOVA help us to identify which parameter is important for us after literature review following ANOVA table is obtained for MRR and Surface roughness .Minitab 15 software is used for statistical calculation purpose.

Table 5.4 Analysis of Variance for S/N ratio Using Adjusted SS for Tests (MRR):

Source	D.o.F	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	4	166.488	166.488	41.622	1526.45	0.000
Feed Rate	4	81.790	81.790	20.448	749.90	0.000
Depth of Cut	4	280.890	280.890	70.223	2575.36	0.000
Error	12	0.327	0.327	0.027		
Total	24	529.496				

S = 0.165128   R-Sq = 99.94%   R-Sq(adj) = 99.88%

Table 5.6 Analysis of Variance for Means Using Adjusted SS for Tests (MRR)

Source	D.o.F	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	4	19483127	19483127	4870782	10.94	0.001
Feed Rate	4	7847055	7847055	1961764	4.41	0.020
Depth of Cut	4	32151961	32151961	8037990	18.06	0.000
Error	12	5341510	5341510	445126		
Total	24	64823652				

S = 667.177   R-Sq = 91.76%   R-Sq(adj) = 83.52%

5.2.4. Determination of the Optimum Value of Input Parameters for Material Removal Rate (MRR)

Fig-5.1 and Fig- 5.2 shows two graphs, which contains the curve between mean of signal to noise ratio data and input parameters (control factors) shows the curve between the mean of mean. The values of the graphs and the objective of using the S/N ratio as a performance measurement is to develop products and the processes insensitive to noise factors. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance. Consequently, the level that has a higher value determines the optimum level of each factor.

For Example, in fig. 5.1 level Five for Spindle speed (N_5=1400 RPM) has the maximum S/N ratio value, which indicated that the machining performance at such level produced larger metal removal rate. Furthermore, level Five of spindle speed (N_5=1400 RPM) has indicated the optimum situation in term of mean value. Similarly, the level Four of feed rate (F_4=0.16 mm/rev) and the level five of depth of cut (DOC_5=0.3mm) have also indicated the optimum situation of S/N ratio and mean value. Therefore the optimum cutting for larger metal removal rate will be spindle speed 1400 RPM, feed rate 0.16mm/rev and depth of cut 0.3mm as shown in Figures.

5.3. Layout of the L_{25} Orthogonal Array (OA) with measured Surface Roughness (Ra)

Each run will have three values collected for surface finish. Therefore, a total of (5**3) =25 data values were collected for surface finish and each run will have two data values collected for the material removal rate, therefore a total of (5**3=25) data values for MRR, which are conducted for analysis in the experiment.

Table 5.7 L25 Orthogonal Array(OA) with measured Surface Roughness(Ra)

Exp Run	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut(mm)	Ra (µm)
1	0.1	600	0.1	1.132
2	0.1	800	0.12	1.159
3	0.1	1000	0.14	1.155
4	0.1	1200	0.16	1.122
5	0.1	1400	0.18	1.113
6	0.15	600	0.12	1.171
7	0.15	800	0.14	1.16

8	0.15	1000	0.16	1.165
9	0.15	1200	0.18	1.152
10	0.15	1400	0.1	0.585
11	0.2	600	0.14	1.213
12	0.2	800	0.16	1.201
13	0.2	1000	0.18	1.175
14	0.2	1200	0.1	0.991
15	0.2	1400	0.12	0.728
16	0.25	600	0.16	1.311
17	0.25	800	0.18	1.221
18	0.25	1000	0.1	1.149
19	0.25	1200	0.12	1.103
20	0.25	1400	0.14	0.981
21	0.3	600	0.18	1.432
22	0.3	800	0.1	1.163
23	0.3	1000	0.12	1.152
24	0.3	1200	0.14	1.141
25	0.3	1400	0.16	1.081

After the experimental results have been obtained, analysis of the results was carried out analytically as well as graphically. Graphical analysis is done by MINITAB, shows interactions of all parameters. Then ANOVA of the experimental data has been done to calculate the contribution of each factor in each response. Then we calculated S/N ratio for MRR and surface roughness of specimens.

Then we obtain optimal conditions has been calculated for MRR and surface roughness of specimen. The following table shows readings of MRR and surface roughness at each experiment, it also shows S/N ratio for MRR and surface roughness

5.3.1 Discussion and Analysis for Surface Roughness (Ra) by Minitab15 Software:

Here the desirable objective is to optimize the response variables Surface Roughness(R_a). Hence smaller-the-better types Signal to Noise (S/N) ratio was applied for transforming the raw data for surface roughness as smaller values of Surface Roughness (R_a) as desirable.

5.3.2. Calculation of Signal to Noise (S/N) Ratio for R_a

The S/N ratio is obtained using Taguchi's methodology. Here, the term 'signal' represents the desirable value (Mean) and the 'noise' represents the undesirable value (standard deviation). Thus, the Signal to Noise (S/N) ratio represents the amount of variation presents in the performance characteristic. Here the desirable objective is to optimize the response variables R_a. Hence smaller-the-better types S/N ratio was applied for transforming the raw data for surface roughness as smaller values of R_a as desirable. The values of S/N ratio and mean corresponding to different experiment runs have been tabulated in Table 5.8.

Table 5.8 Taguchi Orthogonal Array Design for Signal to Noise(S/N) Ratio (Ra)

Exp. Run	Depth of cut(mm)	Speed (rev/min)	Feed (mm/rev)	Ra (µm)	S/N Ratio	Mean
1	0.1	600	0.1	1.132	-1.07693	1.132
2	0.1	800	0.12	1.159	-1.28167	1.159
3	0.1	1000	0.14	1.155	-1.25164	1.155
4	0.1	1200	0.16	1.122	-0.99986	1.122
5	0.1	1400	0.18	1.113	-0.9299	1.113
6	0.15	600	0.12	1.171	-1.37114	1.171
7	0.15	800	0.14	1.16	-1.28916	1.16
8	0.15	1000	0.16	1.165	-1.32652	1.165

9	0.15	1200	0.18	1.152	-1.22905	1.152
10	0.15	1400	0.1	0.585	4.65688	0.585
11	0.2	600	0.14	1.213	-1.67722	1.213
12	0.2	800	0.16	1.201	-1.59086	1.201
13	0.2	1000	0.18	1.175	-1.40076	1.175
14	0.2	1200	0.1	0.991	0.07853	0.991
15	0.2	1400	0.12	0.728	2.75737	0.728
16	0.25	600	0.16	1.311	-2.35205	1.311
17	0.25	800	0.18	1.221	-1.73431	1.221
18	0.25	1000	0.1	1.149	-1.2064	1.149
19	0.25	1200	0.12	1.103	-0.85151	1.103
20	0.25	1400	0.14	0.981	0.16662	0.981
21	0.3	600	0.18	1.432	-3.11886	1.432
22	0.3	800	0.1	1.163	-1.31159	1.163
23	0.3	1000	0.12	1.152	-1.22905	1.152
24	0.3	1200	0.14	1.141	-1.14571	1.141
25	0.3	1400	0.16	1.081	-0.67651	1.081

5.3.3. Effect of Input Factor on Surface Roughness (R_a)

Here the desirable objective is to optimize the response variables Ra. Hence smaller-the-better types S/N ratio was applied for transforming the raw data for surface roughness as smaller values of Ra as desirable.

Table 5.9 Response Table for Mean (Ra)

Level	**Depth of Cut(mm)**	**Cutting Speed (rpm)**	**Feed Rate(mm/rev)**
1	1.1362	1.2518	1.0040
2	1.0466	1.1808	1.0626

3	1.0616	1.1592	1.1300
4	1.1530	1.1018	1.1760
5	1.1938	0.8976	1.2186
Delta	0.1472	0.3542	0.2146
Rank	3	1	2

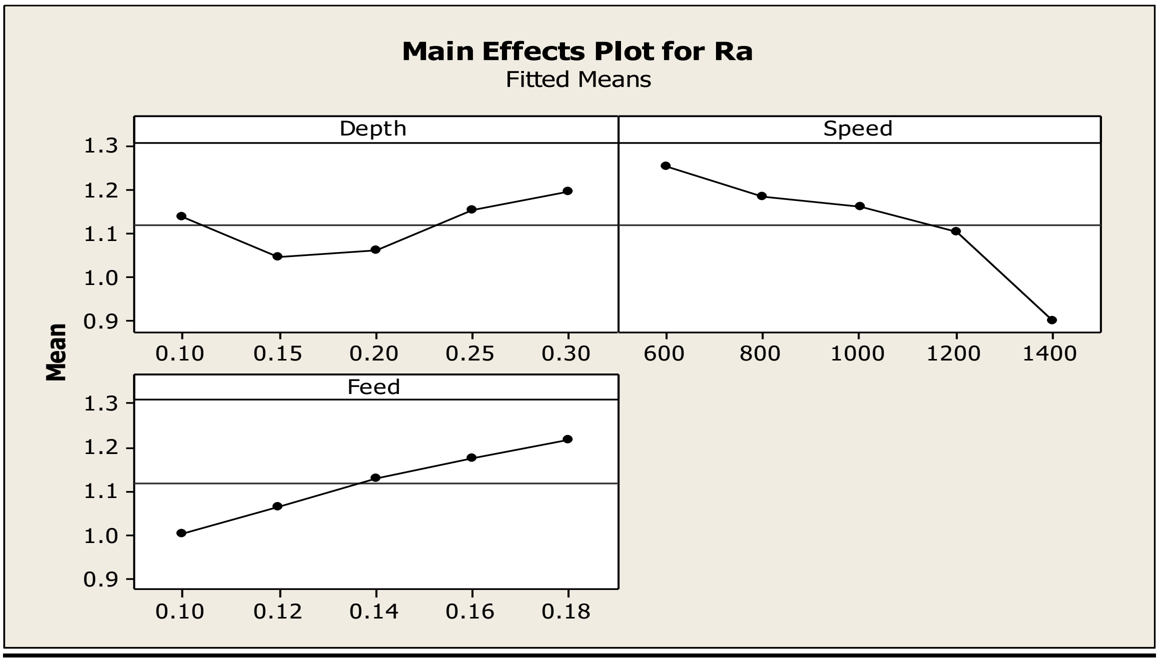

Figure 5.3 Main Effect Plot for Mean (Ra)

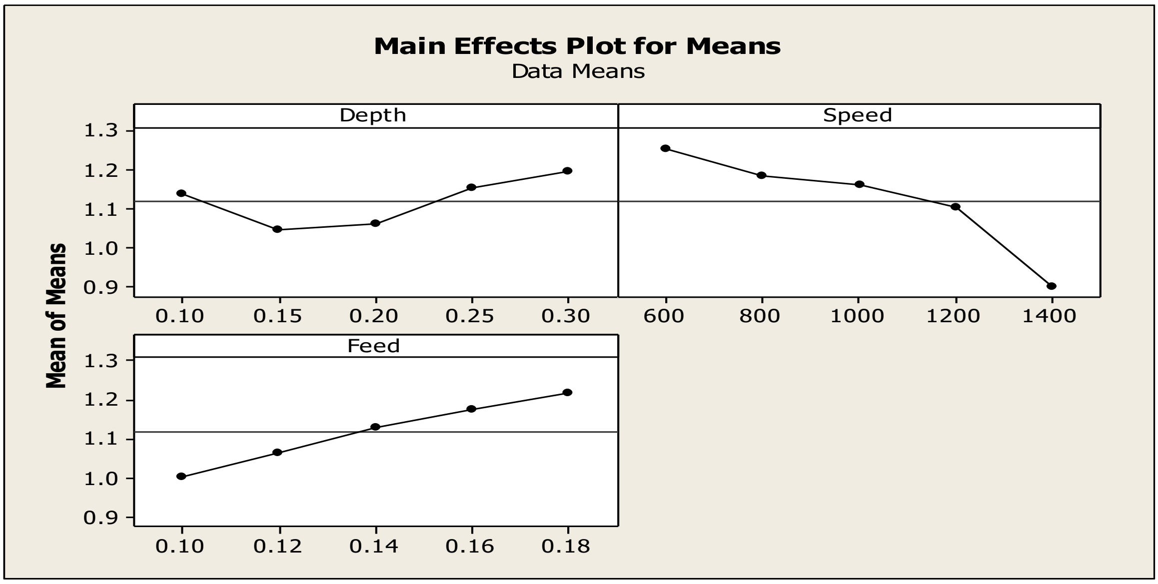

Figure 5.4 Main Effect Plot for Means of Means

Table 5.10 Response Table for S/N Ratio: Smaller is better (Ra)

Level	**Depth of Cut(mm)**	**Speed(rev/min)**	**Feed(mm)**
1	-1.1080	-1.9192	0.2281
2	-0.1118	-1.4415	-0.3952
3	-0.3666	-1.2829	-1.0394
4	-1.1955	-0.8295	-1.3892
5	-1.4963	1.1949	-1.6826
Delta	1.3845	3.1141	1.9107
Rank	3	1	2

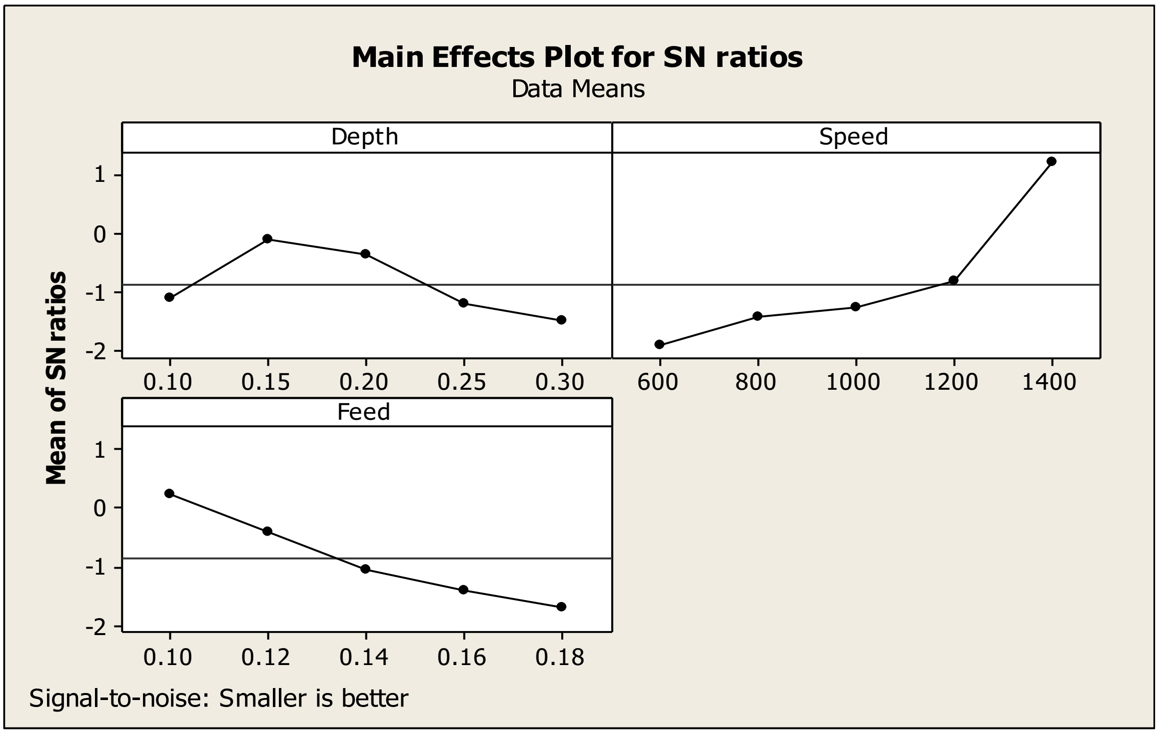

Figure 5.5 Main Effect Plot for S/N Ratio(Ra)

5.3.4. Analysis of Variance Using Adjusted Sum of Squares(SS) for Test

The purpose of the analysis of variance (ANOVA) is to determine which cutting parameters significantly affect the surface roughness (R_a). A better feel for the relative effect of the different factors can be obtained by the decomposition of the variance, which is commonly known as analysis of variance (ANOVA).

Table Show the results of ANOVA analysis of Signal to noise ratio data for means. The most significant input factor is feed rate for surface roughness. The purpose in conducting ANOVA is to determine the relative magnitude of each factor on the objective function and to estimate the error variance. In Robust Design, ANOVA also used to choose from among many alternatives the most appropriate quality characteristics and S/N ratio for a specific problem. ANOVA used to investigate which machining parameters affected the observed values significantly. [22] In this experiment the percentage Contribution of Cutting Speed is Maximum. The most Significant factor input is Cutting Speed and after that feed rate for surface roughness. The effect of depth of cut is very less on surface roughness in this experiment.

ANOVA Table (Values are Obtained by Software Minitab) for:

a. S/N Ratio.
b. Mean Ra.

Table 5.11 Analysis of Variance for S/N ratio Using Adjusted SS for Tests (Ra)

Source	D.o.F	Seq SS	Adj SS	Adj MS	F	P
Depth of Cut	4	0.077903	0.077903	0.01947	3.55	0.039
Cutting Speed	4	0.361910	0.361910	0.090478	16.47	.000
Feed Rate	4	0.148466	0.148466	0.037117	6.76	.004
Error	12	0.065914	0.065914	0.005493		
Total	24	0.654193				

S = 0.0741135 R-Sq = 89.92% R-Sq(adj) = 79.85%

Table 5.12 Analysis of Variance for Mean Using Adjusted SS for Tests (Ra)

Source	D.o.F	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	13.6633	13.6633	6.8317	12.11	0.076
Feed Rate	2	17.8081	17.8081	8.9041	15.78	0.060
Depth of Cut	2	4.5447	4.5447	2.2724	4.03	0.199
Error	2	1.1282	1.1282	0.5641		
Total	8	37.1444				

S = 0.751064   R-Sq = 96.96% R-Sq(adj) = 87.85%

5.3.5. Determination of the Optimum Value of Input Parameters for Surface Roughness

Fig-5.3 and Fig-5.4 shows three graphs, which contains the curve between mean of signal to noise ratio data and input parameters (control factors) shows the curve between the mean of mean and the control factors. The values of the graphs and the objective of using the S/N ratio as a performance measurement is to develop products and the processes insensitive to noise factors. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance. Consequently, the level that has a higher value determines the optimum level of each factor.

For Example, in fig.5.3 level Five for Spindle speed (N_5=1400 RPM) has the maximum S/N ratio value, which indicated that the machining performance at such level produced minimum variation of the surface roughness. In addition, the lower surface roughness value has a better machining performance. Furthermore, level Five of spindle speed (N_5=1400 RPM) has indicated the optimum situation in term of mean value. Similarly, the level one of feed rate (F_1=0.1 mm/rev) and the level two of depth of cut (DOC_2=0.15mm) have also indicated the optimum situation of S/N ratio and mean value. Therefore the optimum cutting will be spindle speed 1400 RPM, feed rate 0.1mm/rev and depth of cut 0.15mm as shown in Figures.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATION

6.1 Conclusion

In this study were to determine the optimum condition of machining parameters and the significance of each parameter to the performance of machining characteristics. The total experiment runs performed in this study was 25 trials using randomized parameters which done by MINITAB 15 software. The following conclusion are drawn based on the performance of machining characteristics studies**:**

6.1.1. For Metal Removal Rate (MRR)

In Material Removal Rate from the all selected parameters, Depth of Cut is the most significant input factor affecting the Turning of AISI 304 Austenitic stainless steel followed by Cutting Speed and Feed.

- The optimum machining parameter is 1400 rpm Cutting Speed, 0.16 mm/rev Feed Rate and 0.3 mm Depth of Cut.
- The contribution of Feed Rate, Depth of Cut and Cutting Speed is 15.446, 53.04%, 31.442% respectively.

6.1.2 For Surface Roughness (Ra)

For Surface Roughness From the all selected parameters, Speed is the most significant input factor affecting the Turning of AISI 304 followed by Feed rate and Depth of Cut.

- The optimum machining parameter is 1400 rpm Cutting Speed, 0.1 mm/rev Feed Rate and 0 .15 mm Depth of Cut.
- The contribution of Cutting Speed ,Feed Rate and Depth of Cut is 55.32%, 22.694%, 11.9% respectively.

6.2 Scope for Future Work

Since surface finish is a crucial factor for any product manufactured the way to increase surface finish may be a great field of study. Study can be continued on surface roughness ,material removal rate ,life of cutting tool and its wear mechanism.

REFERENCES

[1] Nithyanandhan T. et al "Optimization of Cutting Forces, Tool Wear and Surface Finish in Machining of AISI 304 Stainless Steel Material Using Taguchi's Method", International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 4, June 2014, page 488-493

[2] D. Philip Selvaraj et al "Optimization of surface roughness of AISI 304 austenitic stainless steel in dry turning operation using Taguchi method", Journal of Engineering Science and Technology Vol. 5, No. 3 (2010) page 293 – 301, © School of Engineering, Taylor's University College

[3] Samrudhi Rao et al "An Overview of Taguchi Method: Evolution, Concept and Interdisciplinary Applications", International Journal of Scientific & Engineering Research, Volume 4, Issue 10, October-2013, page 621-626

[4] Krishankant et al "Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters", International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-1, October 2012, page 263-274

[5] Quazi T Z et al "a case study of Taguchi method in the optimization of turning parameters", International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 2, February 2013), page 616-626

[6] Atul Kulkarni et al "Design optimization of cutting parameters for turning of AISI 304 austenic stainless steel using Taguchi method", Indian Journal of engineering & material sciences, vol. 20, August 2013, page 252-258

[7] W. H. Yang et al "Design optimization of cutting parameters for turning operations based on Taguchi method", Journal of materials processing technology 84(1998), page 122-129

[8] M. Adinarayana et al "Parametric analysis and multi objective optimization of cutting parameters in turning operation of AISI 4340 ally

steel with CVD cutting tool", International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308, page 449-456

[9] Vikas B. Magdum et al "Evaluation and Optimization of Machining Parameter for turning of EN 8 steel", International Journal of Engineering Trends and Technology (IJETT) - Volume4 Issue5- May 2013, page 1564-1568

[10] Sijo M. T. et al "Taguchi Method for Optimization of Cutting Parameters in Turning Operations", AMAE Int. J. on Manufacturing and Material Science, Vol. 01, No. 01, May 2011, page 44-46

[11] Elso Kuljanic et al "Machinability of difficult machining materials", 14th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2010, Mediterranean Cruise, 11-18 September 2010, page I-1 to I-14

[12] Kompan Chomasmutr et al "Optimization Parameters of tool life Model Using the Taguchi Approach and Response Surface Methodology", International Journal of Computer Science Issues, Vol. 9, Issue 1, No 3, January 2012, page 120-125

[13] Sunil Kumar Sharma et al "Optimization of Process Parameters in Turning of AISI 8620 Steel Using Taguchi and Grey Taguchi Analysis", Int. Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622, Vol. 4, Issue 3(Version 6), March 2014, page 51-57

[14] Anand S. Shivade et al "Optimization of Machining Parameters for Turning using Taguchi Approach", International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-3, Issue-1, March 2014, page 145-149

[15] A.Y. Mustafa and T. Ali, "Determination and optimization of the effect of cutting parameters and workpiece length on the geometric tolerances and

surface roughness in turning operation”, International Journal of the Physical Sciences Vol. 6(5), 4 March, 2011, pp. 1074-1084

[16] Ali Abdallah, Bhuvenesh Rajamony, and Abdulnasser Embark, “Optimization of cutting parameters for surface roughness in CNC turning machining with aluminum alloy 6061 material”, IOSR Journal of Engineering, Vol. 04, Issue 10, October 2014, pp. 01-10.

[17] Biswajit Das, R. N. Rai & S. C. Saha, “Analysis Of Surface Roughness On Machining Of Al-5cu Alloy In CNC Lathe Machine”, International Journal of Research in Engineering and Technology, Volume: 02 Issue: 09, Sep-2013, pp. 296-299.

[18] Dr. M. Naga Phani Sastry, K. Devaki Devi, Dr, K. Madhava Reddy, “Analysis and Optimization of Machining Process Parameters Using Design of Experiments”, Industrial Engineering Letters, Vol 2, No.9, 2012, pp. 23-32.

[19] Durai Matinsuresh BABU, Mouleeswaran Senthil Kumar and Jothiprakash Vishnuu, “Optimization Of Cutting Parameters For CNC Turned Parts Using Taguchi’s Technique”, Internation journal of engineering, Fascicule 3, 2012, pp. 493-496.

[20] Gaurav Vohra, Palwinder Singh and Harsimran Singh Sodhi, “Analysis and Optimization of Boring Process Parameters By Using Taguchi Method”, International Journal of Computer Science and Communication Engineering, 2013, pp. 232-237.

[21] H.M.Somashekara and Dr. N. Lakshmana Swamy, “Optimizing Surface Roughness In Turning Operation Using Taguchi Technique and ANOVA”, International Journal of Engineering Science and Technology, Vol. 4 No.05 May 2012, pp. 1967-1973.

[22] Madhav Murthy, K.Mallikharjuna Babu and R.Suresh Kumar, “Optimization of Machinability Parameters of Al6061 using Taguchi Technique”, International Journal of Current Engineering and Technology, Issue-3, April 2013, pp. 63-66

[23] Md. Tayab Ali and Dr. Thuleswar Nath, "Cutting Parameters Optimization for Turning AA6063-T6 Alloy by Using Taguchi Method", International Journal of Research in Mechanical Engineering & Technology, Vol. 4, Issue 2, May - October 2014, pp. 82-86.

[24] Mohan Singh, Dharmpal Deepak , Manoj Kumar Singla, Manish Goyal and Vikas Chawla, "An Experimental Estimate Mathematical Model Of Surface Roughness For Turning Parameters On CNC Lathe Machine", National Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering, February 19-20, 2010, pp. 336-343.

[25] N. Radhika, R. Subramaniam and S. Babudeva senapathi, "Machining parameter optimisation of an aluminium hybrid metal matrix composite by statistical modelling", Industrial Lubrication and Tribology, 65/6 (2013), pp. 425–435.

[26] N.Prabhakar, B. Sreenivasulu & U.Nagaraju, "Application of ANOVA and ANN Technique for Optimize Of CNC Machining Parameters", International Journal Of Innovations In Engineering Research And Technology, Volume 1, Issue 1 Nov-2014, pp. 1-12.

[27] Narayana B. Doddapattar and Chetana S. Batakurki, "Optimization Of Cutting Parameters For Turning Aluminum Alloys Using Taguchi Method", International Journal of Engineering Research & Technology, Vol. 2 Issue 7, July – 2013, pp. 1399-1407.

[28] Ranganath M S, Vipin and R. S. Mishra, "Optimization of Process Parameters in Turning Operation of Aluminium (6061) with Cemented Carbide Inserts Using Taguchi Method and ANOVA", International Journal of Advance Research and Innovation, Volume 1, Issue 1, 2013, pp. 13-21.

[29] Ravindra Thamma, "Comparison Between Multiple Regression Models to Study Effect of Turning Parameters on the Surface Roughness", Proceedings of The 2008 IAJC-IJME International Conference, 2008.

[30] Rishu Gupta, Ashutosh Diwedi, "Optimization of Surface Finish and Material Removal Rate with Different Insert Nose Radius for Turning

Operation on CNC Turning Center”, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 6, June 2014, pp. 13540-13547.

[31] S.V.Alagarsamy and N.Rajakumar, “Analysis of Influence of Turning Process Parameters on MRR & Surface Roughness Of AA7075 Using Taguchi’s Method and RSM”, International Journal of Applied Research and Studies, Volume 3, Issue 4, Apr-2014, pp. 1-8.

[32] Senthil Kumar. M.P. and Rajendran, “Optimization of CNC Turning Parameters on Aluminum 7015 Hybrid Metal Matrix Composite Using Taguchi Robust Design”, International Journal of Engineering and Technology, Vol. 6, No 4, Aug-Sep 2014, pp. 1675-1682.

[33] Vipindas M P and Dr. Govindan P, “Taguchi-Based Optimization of Surface Roughness in CNC Turning Operation”, International Journal of Latest Trends in Engineering and Technology, Vol. 2 Issue 4 July 2013, pp. 454-463.