OPTIMIZATION OF MACHINING PARAMETERS ON CNC LATHE AISI 316L MATERIAL WITH COATED CARBIDE INSERTS USING TAGUCHI METHOD AND GRA METHOD

A Project report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the Project Report entitled **"OPTIMIZATION OF MACHINING PARAMETERS ON CNC LATHE AISI 316L MATERIAL WITH COATED CARBIDE INSERTS USING TAGUCHI METHOD AND GRA METHOD"** being submitted by PAIDI SAI CHARAN (317126520104), NARENDRA KUMAR CHOWDARY (317126520101), GANDETTI MAHESH RAO (317126520077), KOTTIGUMADA PRANAY CHANDRA (317126520092), PEDDINTI DHANUNJAYA RAO (317126520108) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.R.D.V.PRASAD**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ACKNOWLEDGEMENT

We would like to express our deep gratitude to our project guide **Mr. R. D. V. Prasad**, Asst. Professor, Department of Mechanical Engineering, ANITS, for his guidance with unsurpassed knowledge and immense encouragement. We are grateful to **Dr. B. Nagaraju**, Head of the Department, Mechanical Engineering, for providing us with the required facilities for the completion of the project work.

We are very much thankful to the **Principal and Management**, ANITS, for their encouragement and cooperation to carry out this work.

We express our thanks to all **teaching faculty** of the Department of Mechanical Engineering, whose suggestions during reviews helped us in accomplishment of our project. We would like to thank **all non-teaching staff** of the Department of Mechanical Engg., ANITS for providing great assistance in the accomplishment of our project.

We would like to thank our parents, friends, and classmates for their encouragement throughout our project duration. At last but not the least, we thank everyone for supporting us directly or indirectly in completing this project successfully.

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ABSTRACT

The assessment of machinability rating of an engineering material is the fundamental activity to increase the productivity, decrease the machining cost and to optimise materials selection in design of mechanical parts. Therefore, this work focuses on the study of ***surface roughness parameter (R_a), Tool Temperatures (TT) and Metal Removal rate (MRR)*** while machining ***AISI 316L stainless steel bar*** for various combination of machining parameters like ***feed (f), depth of cut (doc), and speed (N)*** using Taguchi philosophy with ***coated carbide inserts under dry conditions***. Each time, a new insert is used while machining operation to avoid tool wear.

The Surface roughness tester, thermocouple and CNC lathe are used to measure the surface roughness and temperature. The responses thus generated are used to analyse the effect on variation in machining parameters combinations in turning operation on a CNC lathe.

Taguchi design method is used to generate design of experiments (DOE) based on Orthogonal Arrays (OA) and Signal-to-noise ratio (SN ratio). Analysis of contribution and significance of process parameters based on experimental results are analysed using Analysis of Variance (ANOVA). A Multi-response optimization carried using Grey Relational Analysis (GRA).

OBJECTIVES

- To study the surface roughness parameter, tool temperature and MRR in turning operation of AISI 316L Stainless steel bar, based on the Taguchi DOE with machining parameters as feed (mm/rev), spindle speed (rpm) and depth of cut (mm) while using new coated carbide tool inserts for avoiding tool wear.
- ANOVA for identification of significance and contribution of process parameters on responses.
- Multi-response optimization using GRA.
- Studying the relation between responses.

CONTENTS

INTRODUCTION

Chapter 1. INTRODUCTION TO CNC AND ITS OPERATION

1.1. CNC Overview

Broadly speaking a "CNC Router" is a computer controlled machine that has a router or spindle mounted on it that holds a cutting tool (router bit). It is typically set up with 3 directions of movement referred to as the X, Y and Z axis. The position of the router is determined by a computer telling the motors mounted on each axis how much to move in each direction.

Using this method of positioning, any location within the machine's work area (envelope) can be defined and the router can be moved within that space. As the machine is driven by a computer telling it where to move, the operator uses a software program to draw the shapes they want to cut and create the path that the machine will follow.

The image below shows a typical layout for a CNC (there are many variations though) and a number of the key components along with an indicator of the possible directions of movement (X, Y and Z).

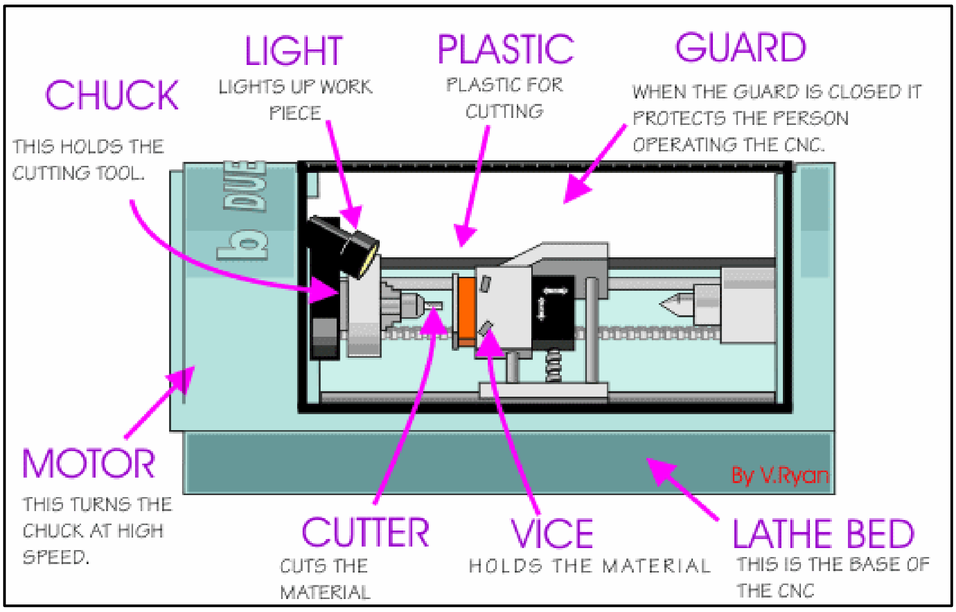


Figure1.1. CNC Lathe Diagram

The CNC machine comprises the computer in which the program is fed for cutting of the metal of the job as per the requirements. All the cutting processes that are to be carried out and all the final dimensions are fed into the computer via the program. The computer thus knows what exactly is to be done and carries out all the cutting processes. The CNC machine works like the Robot, which has to be fed with the program and it follows all your instructions.

Figure1.2. CNC Lathe

Some of the common machine tools that can run on the CNC are: Lathe, Milling machines, Drilling Machine etc. The main purpose of these machines is to remove some of the metal so as to give it proper shape such as round, rectangular, etc. In the traditional methods these machines are operated by the operators who are experts in the operation of these machines. Most of the jobs need to be machined accurately, and the operator should be expert enough to make the precision jobs. In the CNC machines the role of the operators is minimized. The operator has to merely feed the program of instructions into the computer, load the required tools in the machine, and the rest of the work is done by the computer automatically. The computer directs the machine tool to perform various machining operations as per the program of instructions fed by the operator.

1.2. Key Areas of Knowledge

As with any subject, the more time you invest in learning about CNC and the related technologies, the more you will get from it. To achieve the best results, there are a few key areas which you should concentrate on:

1.2.1. Computer skills

One requirement common to all aspects of CNC work is how to use a computer to perform basic tasks. You will be working with computers and computer programs during almost all the steps of the process as you design your parts and need to understand basic operations such as starting and stopping programs, saving, copying and deleting files, finding files stored on your computer and installing programs and updates. Your CNC machine is also run by a computer, this may be a standalone PC or a dedicated Control Box.

1.2.2. Design & Tool path Software

Before you can cut anything with a CNC, you need to first create the design layout that the machine is going to follow to cut the parts. The software you choose will play a significant role in successfully creating projects with your CNC. Simply put, the design software will allow you to transform "pencil and paper" ideas to a set of instructions used to run the machine. When done correctly, the end result will be a physical product you can touch and hold that has value and purpose and a great sense of achievement.

1.2.3. Operating and Maintaining your CNC Machine

Every CNC machine needs software to directly drive its movement; this is commonly referred to as the 'Control Software'. Some common generic third-party packages that do this include "Mach3" and "WINCNC". Many manufactures create and use their own proprietary systems specific to their own models and these may be installed on an external PC or be loaded onto a dedicated Control Box attached to the machine.

Figure1.3. CNC Control System

Most control systems offer settings that can significantly improve the smoothness and accuracy of your machine when correctly set. While this goes beyond the scope of this guide, it is something worth investigating for your particular CNC. Remember, the best designed project will not cut well on an incorrectly "tuned" machine.

1.2.4. Knowledge of Materials and Tooling

When it comes to obtaining the best possible results, you cannot forget the material you are working with or the tool you are using to cut it. The type of material will factor into every stage of the Project – from initial concept through final finishing.

The common materials people using CNC Routers work with include; wood, plastics, dense foam board and softer (non-ferrous) metals (brass, aluminium, etc.). If you are not already familiar with the type of material you want to use, there are many sources of information that can help you.

Typical questions you must answer for the type of material include proper tool (bit) selection, how fast you can move that tool through that material (Feed Rate and Plunge Rate), how much material you can remove at one time (Pass Depth and Cut Depth) and how fast the bit should be rotating (Spindle or Router speed). Typically suppliers of tooling offer information on the correct settings for the router bits they sell.

1.3. BASIC PRINCIPLES OF CNC

All computer controlled machines are able to accurately and repeatedly control motion in various directions. Each of these motions in various directions is called an axis. Depending on the machine type there are commonly two to five types of axes.

Additionally, a CNC axis may be either a linear axis in which movement is in a straight line, or a rotary axis with motion following a circular path.

1.4. MOTION CONTROL UNIT (MCU)

- The most basic function of any CNC machine is automatic, precise, and consistent motion control.

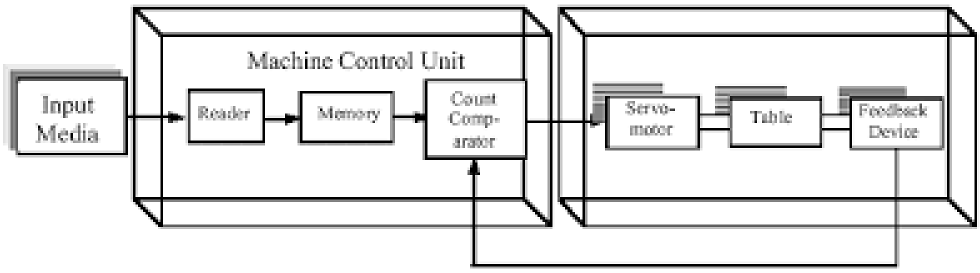


Figure1.4. Block diagram of Motion Control Unit

- Rather than applying completely mechanical devices to cause motion as is required on most conventional machine tools, CNC machines allow motion control in a revolutionary manner.
- All forms of CNC equipment have two or more directions of motion, called axes. These axes can be precisely and automatically positioned along their length of travel.
- The two most common axis types are linear (driven along a straight path) and rotary (driven along a circular path).

1.5. Work Positioning

- The method of accurate work positioning in relation to the cutting tool is called the "rectangular coordinate system." On the vertical mill, the horizontal base line is designated the "X" axis, while the vertical base line is designated the "Y" axis. The "Z" axis is at a right angle, perpendicular to both the "X" and "Y" axes.
- Increments for all base lines are specified in linear measurements, for most machines the smallest increment is one ten-thousandth of an inch (.0001). If the machine is graduated in metric the smallest increment is usually one thousandth of a millimetre (.001mm).
- The rectangular coordinate system allows the mathematical plotting of points in space. These points or locations are called "coordinates." The coordinates in turn relate to the tool center and dictate the "tool path" through the work.

1.6. Tools

- Most are made from high speed steel (HSS), tungsten carbide or ceramic
- Tools are designed to direct waste away from the material.
- Some tools need coolant such as oil to protect the tool and work.

Different types of tools

1.7. Tool Paths, Cutting and Plotting Motions

- A tool path describes the route the cutting tool takes.
- Motion can be described as point to point, straight cutting or contouring.
- Speeds are the rate at which the tool operates e.g. rpm.
- Feeds are the rate at which the cutting tool and workpiece move in relation to each other.
- Feeds and speeds are determined by cutting depth, material and quality of finish needed. e.g. harder materials need slower feeds and speeds.
- Rouging cuts remove larger amounts of material than finishing cuts.
- Rapid traversing allows the tool or workpiece to move rapidly when no machining is taking place

1.8. CNC Programming Basics

- CNC instructions are called part program commands.
- When running, a part program is interpreted one command line at a time until all lines are completed.
- Commands, which are also referred to as blocks, are made up of words which each begin with a letter address and end with a numerical value.
- Each letter address relates to a specific machine function. “G” and “M” letter addresses are two of the most common. A “G” letter specifies certain machine preparations such as inch or metric modes, or absolutes versus incremental modes.
- “M” letter specifies miscellaneous machine functions and work like on/off switches for coolant flow, tool changing, or spindle rotation. Other letter addresses are used to direct a wide variety of other machine commands.

1.9. Important things to know:

- Coordinate System
- Units, incremental or absolute positioning
- Coordinates: X,Y,Z, RX,RY,RZ
- Feed rate and spindle speed.
- Coolant Control: On/Off, Flood, Mist
- Tool Control: Tool and tool parameters
- Programming consists of a series of instructions in form of letter codes

1.10. Preparatory Codes:

- G codes- Initial machining setup and establishing operating conditions
- N codes- specify program line number to executed by the MCU
- Axis Codes: X,Y,Z- Used to specify motion of the slide along X, Y, Z direction
- Feed and Speed Codes: F and S- Specify feed and spindle speed
- Tool codes: T – specify tool number

1.11. Programming Key Letters

- Program number (Used for program identification)
- N - Sequence number (Used for line identification)
- G - Preparatory function
- X - X axis designation
- Y - Y axis designation
- Z - Z axis designation
- R - Radius designation
- F – Feed rate designation
- S - Spindle speed designation
- H - Tool length offset designation
- D - Tool radius offset designation
- T - Tool Designation
- M - Miscellaneous function

1.12. Commonly used G codes

- G00 – Preparatory code to control final position of the tool and not concerned with the path that is followed in arriving at the final destination.
- G01 – Tool is required to move in a straight line connecting current position and final position. Used for tool movement without any machining- point to point control. (linear interpolation)
- G02 – Tool path followed is along an arc specified by I, J and K codes.(circular interpolation)

1.13. Important G codes

- G00 Rapid Transverse G01 Linear Interpolation
- G02 Circular Interpolation, CW G03 Circular Interpolation, CCW
- G17 XY Plane,G18 XZ Plane,G19 YZ Plane
- G20/G70 Inch units
- G21/G71 Metric Units
- G40 Cutter compensation cancel G41 Cutter compensation left G42 Cutter compensation right
- G43 Tool length compensation (plus) G43 Tool length compensation (plus) G44 Tool length compensation (minus) G49 Tool length compensation cancel G80 Cancel canned cycles
- G81 Drilling cycle
- G82 Counter boring cycle G83 Deep hole drilling cycle G90 Absolute positioning G91 Incremental positioning

1.14. Important M codes

- M00 Program stop
- M01 Optional program stop
- M02 Program end
- M03 Spindle on clockwise
- M04 Spindle on counter clockwise
- M05 Spindle stop
- M06 Tool change
- M08 Coolant on
- M09 Coolant off

- M10 Clamps on
- M11 Clamps off
- M30 Program stop, reset to start

1.15. Program Command Parameters

Optimum machine programming requires consideration of certain machine operating parameters including:

- Positioning control
- Compensations
- Special machine features

Positioning control is the ability to program tool and machine slide movement simultaneously along two or more axes. Positioning may be for point-to-point movement or for contouring movement along a continuous path. Contouring requires tool movement along multiple axes simultaneously. This movement is referred to as “Interpolation” which is the process of calculating intermediate values between specific points along a programmed path and outputting those values as a precise motion. Interpolation may be linear having just a start and end point along a straight line, or circular which requires an endpoint, a center and a direction around the arc.

1.16. Rules for programming

1.16.1. Block Format

N135 G01 X1.0 Y1.0 Z0.125 F0.5

- Restrictions on CNC blocks
- Each may contain only one tool move
- Each may contain any number of non-tool move G-codes
- Each may contain only one feed rate
- Each may contain only one specified tool or spindle speed
- The block numbers should be sequential
- Both the program start flag and the program number must be independent of all other commands (on separate lines)
- The data within a block should follow the sequence shown in the above sample block

1.17. CAD/CAM

Two computer-based systems which impact the use of CNC technology are computer aided design and computer aided manufacturing. A computer aided design, or CAD, system uses computers to graphically create product designs and models. These designs can be reviewed, revised, and refined for optimum end use and application. Once finalized, the CAD design is then exported to a computer aided manufacturing, or CAM, system. CAM systems assist in all phases of manufacturing a product, including process planning, production planning, machining, scheduling, management and quality control.

1.18. Turning Process

Turning is a machining process to produce parts round in shape by a single point tool on lathes. The tool is fed either linear in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes. The primary motion of cutting in turning is the rotation of the workpiece, and the secondary motion of cutting is the fed motion.

1.19. TURNING SPEED AND FEEDS

The RPM depends on the cutting speed and the diameter of the part. The RPM setting will change with the diameter of the part. As the diameter of the part gets smaller, the RPM must increase to maintain the recommended surface footage. Again, take the case of the wheel. Think of the part as a wheel and the cutting speed as a distance. A larger wheel (part) will need to turn fewer revolutions per minute to cover the same distance in the same amount of time than a smaller wheel (part). Therefore, to maintain the recommended cutting speed, larger diameter parts must be run at a slower rate and speeds at smaller diameter part. The lathe must be set so that the part will be operating at the proper surface speed. Spindle speed settings on the lathe are done in RPMs. To calculate the proper RPM for the tool and the workpiece we must use the following formula.

RPM = (Cutting Speed) / (n x Diameter of workpiece)

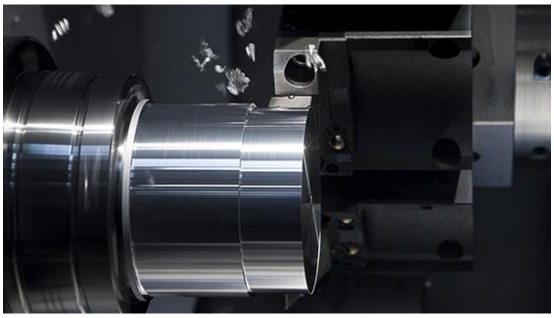


Figure1.5. Machining on a Lathe

If two pieces of different sizes are turning at the same revolutions per minute the larger piece has a greater surface speed. Surface speed is measured in surface feet per minute (SF PM). All cutting speeds work on surface footage principle. Again, cutting speeds depend primarily on the kind of material you are cutting and the kind of cutting tool you are using. The hardness of the work material has a great deal to do with the recommended cutting speed. Harder the work material, slower the cutting speeds. Softer the work material, faster the recommended cutting speeds.

1.20. Summary of Turning parameters and formulae:

1.20.1. Cutting feed:

The distance travelled by the cutting tool or workpiece during one sp indle revolution, measured in inches per revolution. In some operations the tool feeds into the workpiece and in others the workpiece feeds into the tool. For a multi-point tool, the cutting feed is also equal to the feed per tooth, measured in inches per tooth, multiplied by the number of teeth on the cutting tool.

1.20.2. Cutting speed:

The speed of the workpiece surface relative to the edge of the edge of the cutting tool during a cut, measured in surface feet per minute.

1.20.3. Spindle speed:

The spindle and work piece's rotational speed in revolutions per min ute (mPM).The spindle speed is equal to the cutting speed divided by the circumference of the workpiece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the out. If the spindle speed is held constant, then the cutting speed will vary.

1.20.4. Feed rate:

The speed of the cutting tool's movement relative to the workpiece as the tool makes a cut. The feed rate is measured in inches per minute and is the product of the cutting feed (IPR) and the spindle speed (RPM).

1.20.5. Axial depth of cut:

The depth of the tool along the axis of the workpiece as it makes a cut, as in a facing operation. A large axial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is typically machined in several passes as the tool moves to the specific axial depth of cut for each pass.

1.21. Cutting Tool and Geometry

Cutting tools for metal cutting have many shapes, each of which are described by their angles or geometries. Every one of these tools shapes has a specific purpose in metal cutting. The primary machining goal is to achieve the most efficient separation of chips from the workpiece. For this reason, the selection of the right cutting tool geometry is critical. Other chip formation influences include:

- The workpiece material
- The cutting tool material
- The power and speed of the machine
- Various process conditions, such as heat and vibration

1.22. Turning and Single point cutting Tools

Nearly all turning processes use single point cutting tools, that is, tools that cut with only a single edge in contact with the work. Most turning is done with coated index-able carbide inserts, but the tool material may also be high speed steel, brazed carbide, ceramic, cubic boron nitride or polycrystalline diamond. 75% of turning operations use just a few basic tool geometries. When turning with inserts, much of the geometry is built into the tool holder itself rather than actual insert. However, let's focus on the inserts. The geometry of an insert includes:

- The insert's basic shape
- It's relief or clearance angle
- The insert shape

- The insert's inscribed circle or "10 size 0 The insert's nose radius
- The insert's chip breaker design

In turning, insert shape selection is based on the trade-off between strength and versatility. For example, larger point angles are stronger, such as round inserts for contouring and square inserts for roughing and finishing.

The smaller angles (35° and 55°) are the most versatile for intricate work. Turning inserts may be moulded or ground to their working shape. The moulded types are more economical and have wide application. Ground inserts are needed for maximum accuracy and to produce well defined or sharp contours. Several angles are important when introducing the cutting tool's edge into a rotating workpiece. These angles include:

- The angle of inclination
- Rake angle
- Effective rake angle
- Lead or entry angle
- Tool Nose Radius

The ***angle of inclination*** is the angle viewed from the side or front when the tool is in the insert seat or pocket in the tool holder. This inclination can be positive, negative or neutral.

The ***cutting tool's rake angle*** is the angle between the cutting edge and the cut itself. It may also be positive, negative or neutral.

The ***effective rake angle*** is the combination of the tool holder's angle of inclination and the rake built into the insert.

The ***lead or entry angle*** is the angle formed by the point of the cutting tool feed and the cutting edge.

The ***tool nose radius*** is the angles formed by the point of the tool. This radius may be large for strength, or sharp for fine radius turning.

Since a sharp edge is weak and fractures easily, an insert's cutting edge is prepared with particular shapes to strengthen it. These shapes include a honed radius, a chamfer, a land, or a combination of the three.

Insert size is designated by the largest circle which can be inscribed within the perimeter of the insert, called the inscribed circle. Insert size is directly connected to the tool holder size. Insert type tool holders for turning consist of a shank, head; insert pocket, and clamping hardware. Tool holders are either right or left handed or neutral. The size and type of the tool holder are determined by:

- The turning Operation
- The feed direction
- The size of cuts
- Machine tool design
- The need for accessibility
- The shape of the workpiece

In turning, chip breaking is critical to efficient work processing and good finishing qualities. Proper chip breaking results from balancing the depth of cut and the geometry of the tool. The first type, shaped like numerals "6" or "9", represents the ideal chips. The other types indicate the need for speed and feed adjustments, or selection of a different chip breaker design.

1.23. CNC Machines-Advantages/Disadvantages

1.23.1. Advantages:

- High Repeatability and Precision e.g. Aircraft parts
- Volume of production is very high
- Complex contours/surfaces need to be machined. E.g. Turbines
- Flexibility in job change, automatic tool settings, less scrap
- More safe, higher productivity, better quality
- Less paperwork, faster prototype production, reduction in lead times

1.23.2. Disadvantages:

- Costly setup, skilled operators
- Computers, programming knowledge required
- Maintenance is difficult

1.24. GREY RELATIONAL ANALYSIS (GRA)

Grey relational analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown. With this definition, information quantity and quality form a continuum from a total lack of information to complete information – from black through grey to white. Since uncertainty always exists, one is always somewhere in the middle, somewhere between the extremes, somewhere in the grey area.

Grey analysis then comes to a clear set of statements about system solutions. At one extreme, no solution can be defined for a system with any information. At the other extreme, a system with perfect information has a unique solution. In the middle, grey systems will give a variety of available solutions. Grey analysis does not attempt to find the best solution, but does provide techniques for determining a good solution, an appropriate solution for real world problems.

LITERATURE REVIEW

Chapter 2. LITERATURE REVIEW

In CNC machining processes like turning, a proper selection of cutting conditions generates high surface finish and less dimensional error parts subject to fatigue loads, precision fits and aesthetic requirements. Hence many researchers focus on the literature on the measurement of surface roughness using (lathe) and multi-point (milling) cutting tools using different machining parameters like feed, speeds, depth of cut and tool geometry are well documented. Totally the researches in this field can be divided in four groups:

- Trends based on machining theories
- Trends based on experimental tests
- Trends based on designed tests (TAGUCHI based)
- Trends based on intelligent neutral networks

Smair Khraiset et al. [I] focused on evaluating surface roughness and developed a multiple regression model for surface roughness as a function of cutting parameters during the machining of flame hardened medium carbon steel with TiN-AlZO3-TiCN coated inserts. Taguchi methodology was adapted for experimental plan of work and signal-to-noise ratio (S/N) were used to relate influence of turning parameters to the workpiece surface finish and the effects of turning parameters were studied by using the ANOVA.

Ali Motorcu Riza [2] studied the surface roughness in the turning of A181 8660 hardened alloy steels by ceramic based cutting tools with cutting parameters such as cutting speed, depth of cut, feed rate in addition tool's nose radius, using a statistical approach An orthogonal design, signal-to noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness.

W.H. Yang and Y.S. Tarng [3] studied the Taguchi method, as a powerful tool to design optimization for quality and used to find the optimal cutting parameters for turning operations based on orthogonal array, signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) to investigate the cutting characteristics of 854C steel bars using tungsten carbide cutting tools. Through this study, they found not only the optimal cutting parameters for cutting operations can be obtained, but also the main cutting parameters that affect the cutting performance in turning operations. Experimental results are provided to confirm the effectiveness of this approach.

Dilbag Singh et al. [4] investigated the effects of cutting conditions and tool geometry on surface roughness in the finish hard turning of the bearing steel (AISI 52100) with mixed ceramic inserts made up of aluminium oxide and titanium carbon nitride. This study showed that feed is the dominant factor determining the surface finish followed by cutting velocity and the tool rake angle and a mathematical model for the surface roughness were developed by using the response surface methodology.

R.A. Mahdavinejad et al. [5] highlighted the methods of predicted the surface roughness, like based on the trends of machining theories, based on the designed tests, based on Artificial intelligence such as Neutral networks, GA, Fuzzy etc. and based on lab research such as statistics and regression model analysis. The combination of the adaptive Neutral fuzzy system is used to predict the roughness of the dried surface machined in the turning process.

C.X. (Jack) Feng et al. [6] developed an empirical model for the prediction of surface roughness in finish turning basing on workpiece hardness (material), cutting parameters, tool geometry and cutting time by mean of nonlinear regression with logarithmic data transformation and their applications in determining the optimum machining conditions.

A. Manna. B. Bhattacharyya [7] investigated the influence of cutting conditions on surface finish during turning of Al/Sic-MMC with a fixed rhombic tooling system using Taguchi method for optimizing the cutting parameters for effective turning. Taking significant cutting parameters into consideration and using multiple linear regression mathematical models relating to surface roughness height Ra and Rt were established. Several researchers applied Taguchi method not only for lathe machining but also for wire-cut electrical discharge machining (WEDM) of various materials like Aluminium-24345, DC 53 die steel etc. [8] basing on Taguchi's orthogonal array under different conditions of parameters.

Grey relational analysis (GRA) depends on the response values generated for the problem under consideration (here machining responses like R_a, H and Vib in both the turn-mill processes) and determine the combined optimal combination of process parameters with only the set of process parameters levels considered. GRA first converts the response values which are incomparable to each other to comparable values using the concept of normalizing using larger-to-better or smaller-is-better equations. Then the converted and comparable response data are used to determine process parameters combination of the multi-response (I.e. R_a, H and Vib) [9-12].

Shyam lal et al. investigates the effect of the WEDM process parameters on the surface roughness average and the kerf width of the stainless steel (SS 304). Experiment runs based on an orthogonal array of Taguchi method and grey relational analysis method is subsequently applied to determine an optimal WEDM parameter setting. Surface roughness and kerf width are selected as the quality targets. An optimal parameter combination of the WEDM process is obtained using Grey relational analysis. By analysing the grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets is found [13].

In this work a versatile technique namely multi criteria decision making (MCDM) technique which involves the analytical network process (ANP) and technique for order performance by similarity to ideal solution (TOPSIS) method has been used to select the best vendor. Analytical Network Process and TOPSIS method are powerful decision making processes which help people to set priorities on parameters that are to be considered by reducing complex decisions to a series of one-to-one comparisons, thereby synthesizing the result [19-20]. The surface roughness (R_a) and metal removal rate (MRR) produced in a hard turning process under dry conditions using TiN-Al_2O_3-TiCN-TiN coated carbide inserts and high speed steel (HSS) tools. Two parameters are selected for the study: speed and feed with constant depth of cut. These machining parameters are adopted to analyze their influences, significance and contributions on the generated surface roughness and MRR. Full factorial design of experiments (DOE) is used for conducting the experiments and analysis of variance (ANOVA) is used to assess the significance and contribution of each parameter and also their interactions [21].

INTRODUCTION TO TAGUCHI

Chapter 3. INTRODUCTION TO TAGUCHI

3.1. DESIGN OF EXPERIMENTS

In general usage, design of experiments (DOE) or experimental design is the design of any information gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics these terms are usually used for controlled experiments. Former planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components and materials. Other types of study and their design are discussed in the articles on opinion polls and statistics surveys (which are types of observational study), natural experimentation and quasi-experiments (for example, quasi- experimental design); see experiment for the distinction between these types of experiments or studies.

In the design experiments, the experimenter is often inserted in the effect of some process or intervention (the treatment) on some objects (the experimental units) which may be people, parts of people, groups of people, plants , animals etc. Design of experiments is thus a discipline that has a very broad discipline that has a very broad application across all the natural and social sciences and engineering. Designed experiments are also powerful tools to achieve manufacturing cost savings by minimizing process variation and reducing network, scrap and need for inspection. A strategically planned and executed experiment may provide a great deal of information about the effect on a response variable due to one or more factors. Many experiments involve holding certain factors constant and holding the altering levels of another variable thus one-factor at a time (OFAT) approach to process knowledge is however insufficient when compared with changing factor levels simultaneously. Many of the current statistical approaches to designed experiments originate from the work of *R.A. Fischer* in the early part of the 20th century. Fischer demonstrated how taking the time to seriously consider design and execution of an experiment before trying it helped to avoid frequently encountered problems in analysis. Key concepts in creating a designed experiment include blocking, randomization and replication. A well outhunted experiment may provide answers to questions such as:

- What are the key factors in the process?

- At what settings would the process deliver acceptable performance?
- What are the key main and interaction effects in the process?
- What settings would bring about less variation in the output?

A repetitive approach to gain knowledge is encouraged typically involving the following consecutive steps:

- A screening design which narrows the field of variables under assessment.
- A "full factorial" design which studies the response of every combination of factors and factor levels and an attempt to zone in on a region of values where the process is close to optimization
- A response surface design to model the response

  The major design of experiments tam generally includes:
- **Blocking**: When randomizing a factor is impossible or too costly, Mocking lets you restrict randomization by carrying out all of the trials with one setting of the factor and then all the trials with the other setting.
- **Randomization**: Refers to the order in which the trials of an experiment are perforated. A randomized sequence helps to eliminate effects of unknown or uncontrolled variables.
- **Replication**: This is the process of repetition of a complete experimental treatment including the setup.
- **Reflection**: a reflection is a new set of combinations that are run at the opposite levels of the original set.

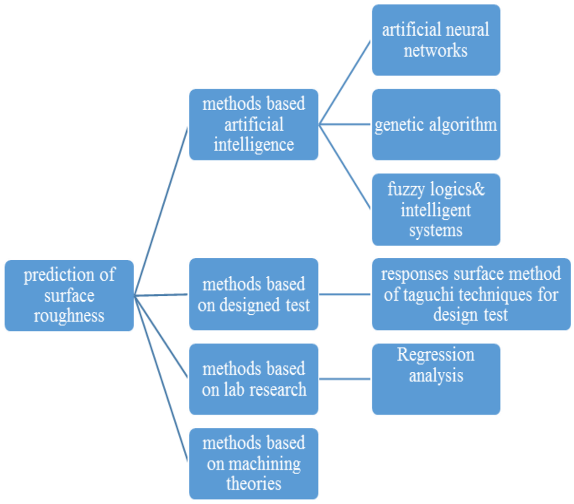


Figure 3.1. Block Diagram of Methods for prediction of surface roughness

3.2. HISTORY OF TAGUCHI

As a researcher in Electronic Control Laboratory in Japan, Dr. Gene chi Taguchi carried out significant research with DOE techniques in the late 1940's. He spent considerable effort to make this experimental technique more user-friendly (easy to apply) and applied it to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi method or Taguchi approach, was introduced in the USA in the early 1980's. Today it is one of the most effective quality building tools used by engineers in all types of manufacturing activities.

The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations.

DOE can be highly effective when you wish to:

- Optimize product and process designs, study the effects of multiple factors (i.e.-variables, parameters, ingredients, etc.) on the performance, and solve production problems by objectively laying out the investigative experiments. (Overall application goals).
- Study Influence of individual factors on the performance and determine which factor has more influence, which ones have less. You can also find out which factor should have tighter tolerance and which tolerance should be relaxed. The information from the experiment will tell you how to allocate quality assurance resources based on the objective data. It will indicate whether a supplier's part causes problems or not (ANOVA data), and how to combine different factors in their proper settings to get the best results (Specific Objectives).

  Further, the experimental data will allow you determine:

- How to substitute a less expensive part to get the same performance improvement you propose.
- How much money you can save the design
- How you can determine which factor is causing most variations in the result
- How you can set up your process such that it is insensitive to the uncontrollable factors

- Which factors have more influence on the mean performance
- What you need to do to reduce performance variation around the target
- How your response varies proportional to signal factor (Dynamic response)
- How to combine multiple criteria of evaluation into a single index
- How you can adjust factor for overall satisfaction of criteria an adjust factors for a system whose of evaluations
- How the uncontrollable factors affect the performance

3.3. Advantage of DOE Using Taguchi Approach

The application of DOE requires careful planning, prudent layout of the experiment, and expert analysis of results. Based on years of research and applications Dr. Gene chi Taguchi has standardized the methods for each of these DOE application steps described below. Thus, DOE using the Taguchi approach has become a much more attractive tool to practicing engineers and scientists.

3.3.1. Experiment planning and problem formulation

Experiment planning guidelines are consistent with modern work disciplines of working as teams. Consensus decisions about experimental objectives and factors make the projects more successful.

3.3.2. Experiment layout

High emphasis is put on cost and size of experiments. Size of the experiment for a given number of factors and levels is standardized. Approach and priority for column assignments are established. Clear guidelines are available to deal with factors and interactions (interaction tables). Uncontrollable factors are formally treated to reduce variation. Discrete prescriptions for setting up test conditions under uncontrollable factors are described. Guidelines for carrying out the experiments and number of samples to be tested are defined

3.3.3. Data analysis

Steps for analysis are standardized (main effect, ANOVA and Optimum). Standard practice for determination of the optimum is recommended. Guidelines for tests of significance and pooling are defined.

EXPERIMENTATION METHODOLOGY

Chapter 4. EXPERIMENTATION METHODOLOGY

4.1. INTRODUCTION

In modern manufacturing there has been strong renewed interaction in high-efficiency machining, while use of advanced materials has increased due to their special mechanical and physical properties. This is mainly affected by selection of suitable machining parameters like cutting speed, feed rate and depth of cut according to cutting tool and workpiece material. The selection of optimum machining parameters will result in longer tool life, better surface finish and higher material removal rate.

In this chapter, we will study in brief and the various understandings available from the metal cutting research work to comprehend fully the nitty-gritty of machining and machining problems parameters. During the course we intend to appreciate the weight of various parameters as speed, feed, depth of cut, cutting parameters, cutting forces etc., which not only influence the quality of the machined product but also the tool life of the tool. The task of confirming the above parameters such as cutting threes and cutting temperatures to the optimum permissible limits is very vital to the machining process.

4.2. WORKPIECE MATERIAL AND CUTTING TOOL

Stainless steels have corrosion resistance and contain a minimum of 0.10% chromium. Stainless steels with austenitic structures have hardness not a guide for speeds. American Iron and Steel Institute (AISI) 316L grade is similar to AISI 316L (chromium-nickel stainless steel) but has an addition element like molybdenum which increases creep strength, hot hardness, corrosion resistance, wear resistance and deepens hardening. The chemical composition of AISI 316L includes Cr 17.5% C 0.06%, Mn 1.5%, Ni 12.2%, Mo 2.5% Si 0.75% and remaining Fe. The workpiece materials with 30mm diameter and 100mm long are shown in fig.4.1. K-type shielded thermocouple was used for recording tool temperature, while MITUTOYO surface roughness tester was used to measure surface roughness parameters, as shown in fig.4.1. Physical Vapour Deposition (PVD) TiAlN Coated carbide inserts with CNMG 120408 MS KC 5010 grade are used for enhanced speed machining and for short chipping. The coated carbide inserts of CNMG120408 MS KC 5010 are used for machining on ACE Microsmatic CNC lathe with Fanuc 0i control system, shown in fig.4.2.

Coated carbide tool features excellent resistance to both mechanical and thermal shock. This gives excellent adhesion with high wear resistance to crater wear and plastic deformation at high temperatures. Also reduces friction and hence the formation of built up edges.

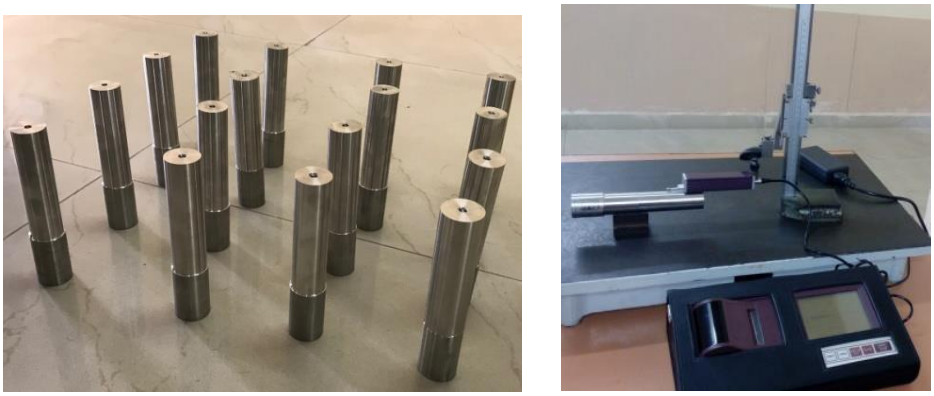


Figure 4.1. ***AISI 316L workpiece after machining and surface roughness tester SJ-301***

Figure 4.2. ***CNC lathe with Fanuc-0i control system and coated carbide inserts.***

Table 4.1. Mechanical Properties of AISI 316L

Temper	Annealed		Cold worked (approx. 20%)	
Material	316L		316L	
Tensile Rm	70	ksi (min)	131	ksi (min)
Tensile Rm	485	MPa (min)	900	MPa (min)
R.p. 0.2% Yield	27	ksi (min)	102	ksi (min)
R.p. 0.2% Yield	182	MPa (min)	700	MPa (min)
Elongation (2”or 4D gl)	35	% (min)	40	% (min)

Figure 4.3.

Table 4.2. Physical Properties (Room Temperature) of AISI 316L

Specific Heat (0-100°C)	500	J.kg-1.°K-1
Thermal Conductivity	16.3	W.m -1.°K-1
Thermal Expansion	15.9	mm/m/°C
Modulus Elasticity	193	GPa
Electrical Resistivity	7.4	μohm/cm
Density	7.99	g/cm3

4.3. Corrosion Resistance

This is potentially the most important property and the reason for use of stainless steel grade 316L. The high corrosion resistance of 316L allows for its use in chloride environments, architecture and marine applications. In cold sea water, 316L is thought of as a "standard marine grade stainless steel" according to Azom, but the property does not hold as true for warm sea water. Stainless steel 316L works well against corrosion in various atmospheric environments, especially in hard and acidic water.

4.4. Heat Resistance

One of stainless steel 316L's strongest properties is its heat resistance. The metal's oxidation resistance holds up through 870 degrees C and it remains serviceable up to 925 degree C. Unlike grade 316, grade 316L can be used throughout the temperature range of 425 to 860 degrees Celsius without worry about aqueous corrosion resistance.

4.5. Weld ability and Machining

Grade 316L cannot typically be welded using oxyacetylene methods of welding. Other methods, like standard fusion and resistance methods, work exceptionally well whether or not filler metals are utilized. Stainless steel 316L can harden if it is machined too quickly, so constant feed rates and low speeds are often used with this grade of steel.

4.6. Other Properties

Stainless steel grade 316L is used more than many other steel grades because its properties are an improvement of others. Grade 316L has a higher creep, tensile strength and stress to rupture at elevated temperatures than austenitic stainless steels made with chromium-nickel. The strength of 316L can be increased by cold working during processes like drawing, stamping and shearing.

4.7. Applications

Typical applications include:

- Control lines
- Process engineering
- Umbilical
- High Performance Liquid Chromatography (HPLC)
- Condensers
- Medical implants (including Pins, screws and implants)
- Semiconductors
- Heat exchangers

4.8. PROCESS OF MACHINING

Workpiece length of 100mm each and then using the Taguchi design of experiments test conditions were generated by taking feed, cutting speed and depth of cut as parameters. As the surface is cylindrical, surface roughness is measured on three diametrical points and the average of them was considered as the surface roughness of the material.

In this project, 16 turning experiments were done on the CNC lathe and the surface roughness readings, tool tip temperature and MRR were measured using surface roughness tester and thermostat respectively, while MRR was calculated theoretically. The responses were used to find the parameter significance using Analysis of Variance (ANOVA) with the help of commercially available data mining technique software packages like MINITAB software.

4.9. Process parameters

The characteristic parameters of a turning operation are (example: straight turning of cylinder with a diameter d (in mm)), Cutting Parameters:

- The depth of cut-DOC (mm)
- The feed per rotation-f (mm/rev)

The cutting speed $\mathbf{v_c}$ in (m/min) which gives the rotational speed N (rpm)

$$N= (1000*v_c/3.14*D)$$

The cutting parameters are at the root of the following performance parameters:

The material removal rate Q (cm^3/min): $Q=d*f*V_c$

N= rotational speed of the workpiece, RPM

f= feed, mm/rev

V= surface speed of the workpiece, m/min = $3.14*D_o*N$ (for max speed)

L=length of the cut, mm

D_o = original diameter of the workpiece, mm

D_f = final diameter of the workpiece, mm

D_{avg} = average diameter of workpiece= $(Di + D_F)/2$

DOC= depth of cut, mm

C_t = cutting time, s

MRR= 3.14*Davg * feed*DOC*speed.

4.10. MEASUREMENT OF CUTTING TEMPERATURES

Cutting temperatures indicate the amount of heat generated during machining. To assay the effectiveness of the cutting fluids coolant, cutting temperatures are measured. Embedded thermocouple is used to measure the temperature if the cutting tool inserts at a nodal point. Digital temperature indicator is used for recording and displaying the temperature of the hot junction of thermocouple.

Table 4.3. Specification of Temperature Indicator

Range:	0-1200^{o} C
Supply Voltage:	230V, AC 50Hz
Input:	Cr-Al (K-type)

Table 4.4. Specification of Thermocouple

Designation:	K-Type, Shielded Thermocouple
Element outside Diameter:	2mm
Element length:	120mm
Element type:	Duplex
Sheath Material:	Recrystallized Alumina
Temperature Range:	-250^{0}C to 1260^{0}C

Figure 4.4. Temperature Indicator

Machining tests are carried out under constant cutting conditions to assess the performance of fluids in machining. Tool temperature is measured at a nodal point. Heat transfer coefficients are calculated for the fluids with different fluids of varying nano -particle concentration.

4.11. SURFACE ROUGHNESS AND ITS IMPORTANCE

Surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be a high frequency, short wavelength component of a measured surface.

Figure 4.5. AISI 316L workpiece after machining with surface roughness tester SJ-301

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion.

Although roughness is often undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cast of a component and its performance in application. Roughness is typically measured in 'RMS" micro inches and is often only measured by manual comparison against a "surface roughness comparator", a sample of known surface roughness. A roughness value can either be calculated on profile (line) or on a surface (area). The profile roughness parameters (Ra, Rq…) are more common. The area roughness parameters (Sa, Sq.., give more significant values.

The surface tester used in the experiment is SJ 301. The surf test SJ 301 is a stylus type surface roughness measuring instrument developed for shop floor use. The measurement results are displayed on the touch panel, and output to the built - in printer.

The surface roughness tester used in the experiment is SJ301. The surf test SJ301 is a stylus type surface roughness measuring instrument developed for shop floor use. The measurements are displayed digitally on the touch panel, and the output to the built-in printer.

Table 4.5. Specifications of Detector

Detection method:	Differential Inductance Method
Measuring range:	350 gm (-200 to +150 pm)
Stylus Material:	Diamond
Tip radius:	5 pm
Measuring force:	4 mN
Radius of the skid curvature:	40 mm

4.12. PROCEDURE

- Insert a new coated carbide tool insert.
- Start machining of the workpiece with the test conditions that were obtained from Taguchi Design of experiments.
- Before the process of machining insert the thermocouple at the tool tip of CNC and ensure that the offset of the tool is set properly.
- Once the machining for each test conditions is completed surface roughness was tested with MITUTOYO tester, Tool temperature using Thermocouple and material removal rate is calculated.
- ANOVA was done for surface roughness, temperature and material removal rate.
- Multi-response optimizations response done using GRA.

4.13. GREY RELATIONAL ANALYSIS (GRA)

GRA is a multi-response optimization technique which generates an optimal process parameter combination for all the responses generated by normalizing response values to make them comparable. Thereby determining the grey relation grade based on the deviation of normalized values and ranking the highest grade as optimal. It was proposed by Deng **[1-3]** and has been proven to be useful for dealing with the problems with poor, insufficient, and uncertain information.

Step 1. Normalization of experimental response data to convert into a sequence of comparable data using equation-4.1:

Response with low noise like surface finish and temperatures adopts;

Lower-is-Better (LB):

$$x_i^*(j) = \frac{[\max(x_i(j)) - x_i(j)]}{[\max(x_i(j)) - \min(x_i(j))]} \quad (4.1a)$$

Response with high noise like metal removal rate adopts;

Higher-is-Better (HB):

$$x_i^*(j) = \frac{[x_i(j) - \min(x_i(j))]}{[\max(x_i(j)) - \min(x_i(j))]} \quad (4.1b)$$

Where X_i (j) is the value of response of i^{th} experiment, max (x_i (j)) and min (x_i (j)) are the smallest and largest values of X_i (j) respectively.

Step 2. The deviation sequence $\Delta_{oi}(k)$ of each response given as:

$$\Delta_{oi}(k) = \|X_0(k) - X_i(k)\| \quad (4.2)$$

Step 3. Grey relational coefficient correlation between responses by giving equal weight age (distinguishable coefficient) as given in equation-4.3.

$$\gamma_i = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (4.3)$$

Where Δ_{min} is the smallest value of the normalized values, Δ_{max} is the maximum value of the normalized values, ζ is the distinguishing coefficient and ranges from 0 to 1 and has been assumed as 0.5 [4].

Step 4. Determination of grey relational grade of combined responses as given in Equation-4.4 and are graded as optimal with highest rank:

$$\alpha_i = \frac{1}{n}\sum_{k=1}^{n} \gamma_i(k) \quad (4.4)$$

Where “n_r” is the total number of responses

Based on the grey relational grade, the ranking has to be given in descending order. The combination of process parameters which has the highest rank is considered to be optimal.

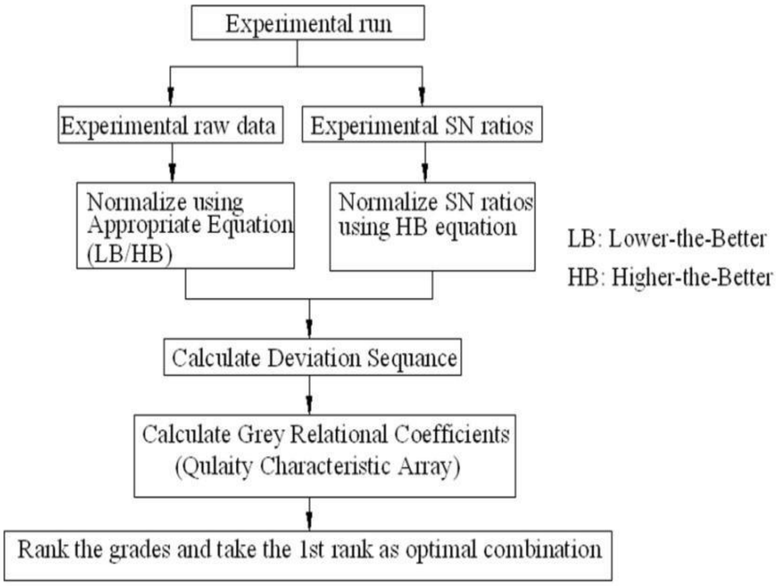


Figure 4.5. Process flow diagram of GRA coupled with PCA for multi response optimization

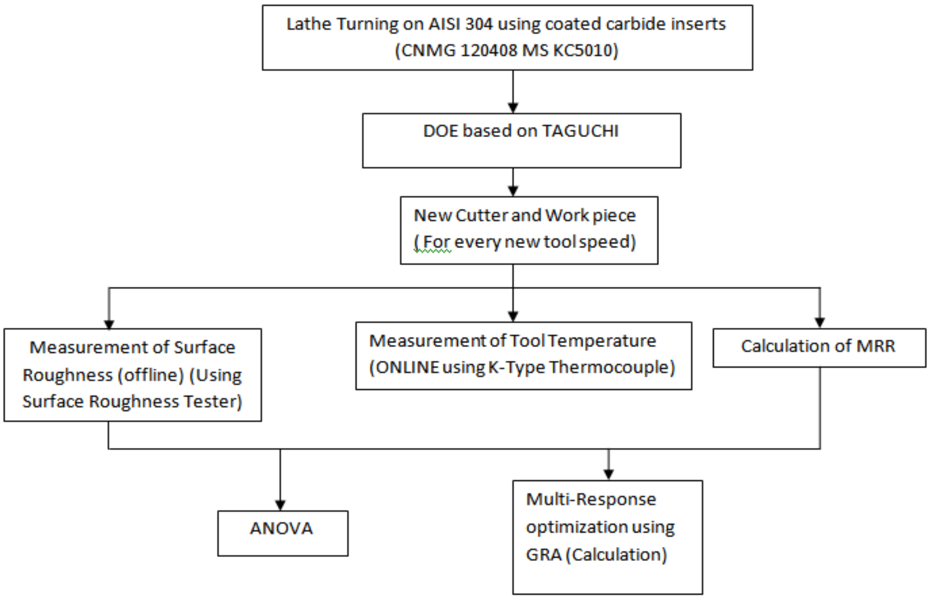


Figure 4.6. Experimental Methodology

APPLICATION OF MINITAB SOFTWARE

Chapter 5. APPLICATION OF MINITAB SOFTWARE

5.1. MINITAB INTRODUCTION

MINITAB provides a wide range of basic and advanced statistics, including exploratory data analysis, basic statistics, regression, analysis of variance (ANOVA), multivariate analysis, time series, cross-tabulations, simulations and distributions. It also has facilities to produce a comprehensive array of graphs.

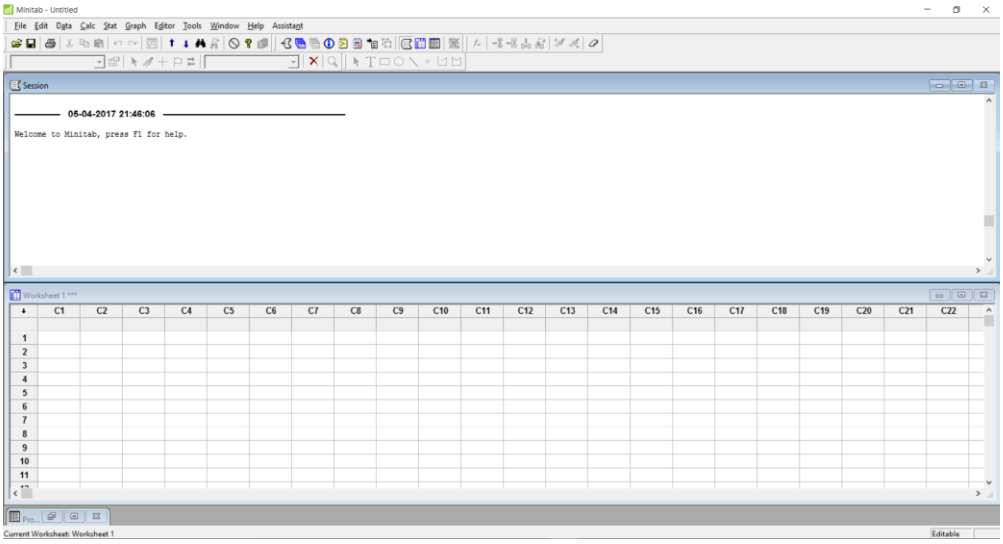


Figure 5.1. MINITAB Worksheet

5.2. Worksheet window

Below the MINITAB menu bar are two sub-windows, named Session and Worksheet1. The session window is where any non- graphical output is displayed. Not that you can also type in commands in this window, but for this tutorial you will use pull-down menus. The worksheet 1 window is a spreadsheet, where you can type in and view your data.

Data in Minitab is stored in a workshop of columns and rows. Typically, each column contains the data for 1 variable and 1 observation in each row. Columns are numbered C1, C2, and C3....., while rows are numbered as 1, 2, 3...... You can change the column names by checking the field below the column number, type the name and hitting return. You can change the name using commands. Column data can easily be edited without any obligations. Data in the column can also be inserted by copying for excel sheets or data in .txt format can also be inserted.

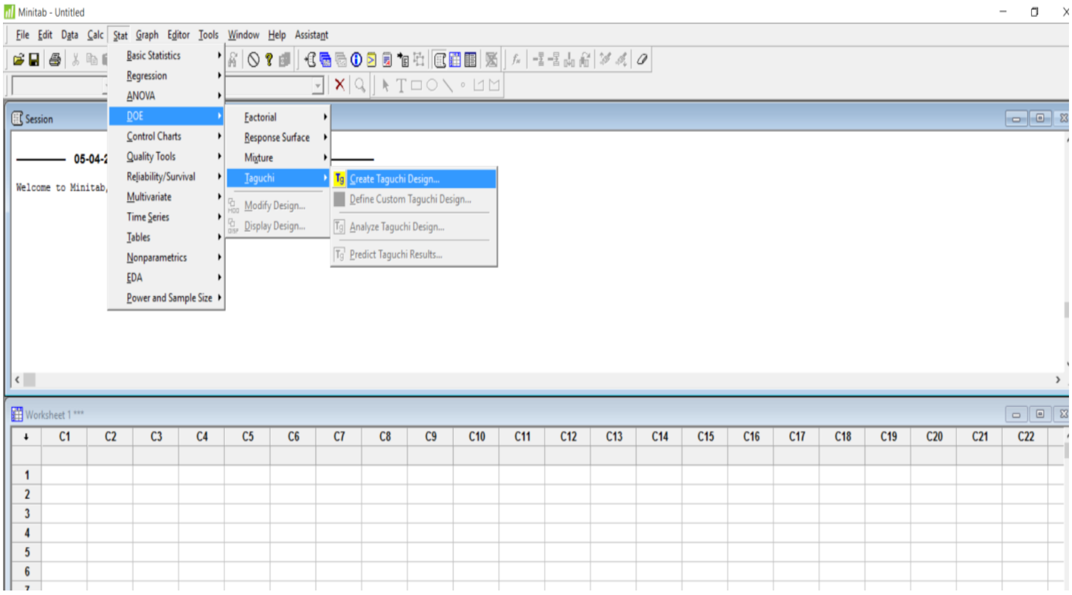


Figure 5.2. ***MINITAB for DOE using Taguchi design***

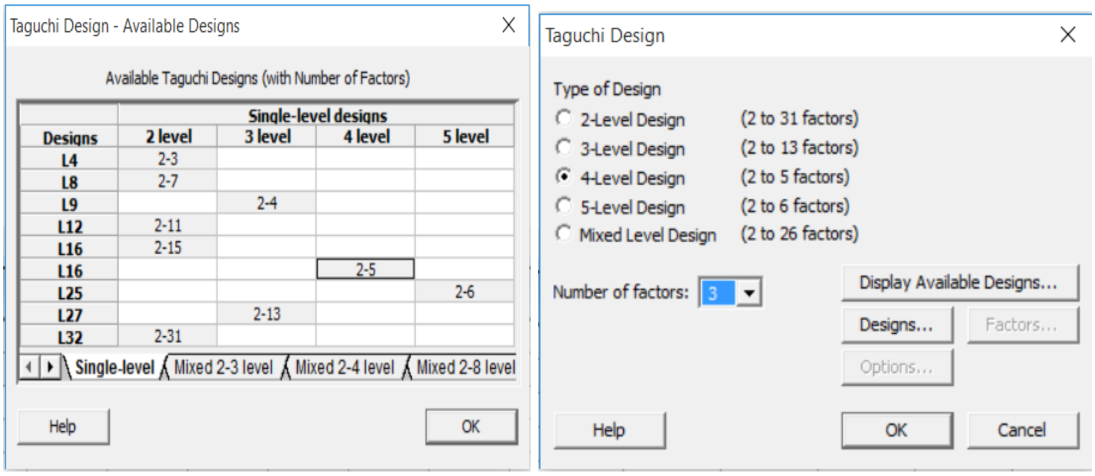
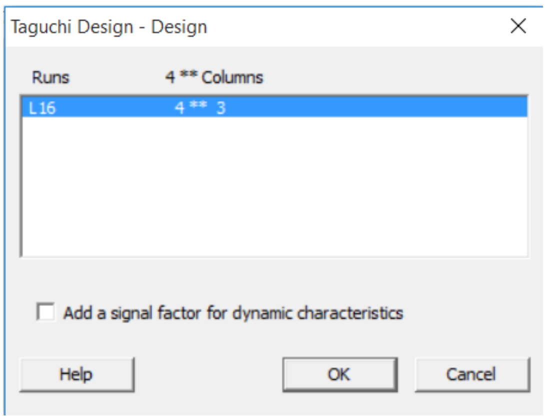
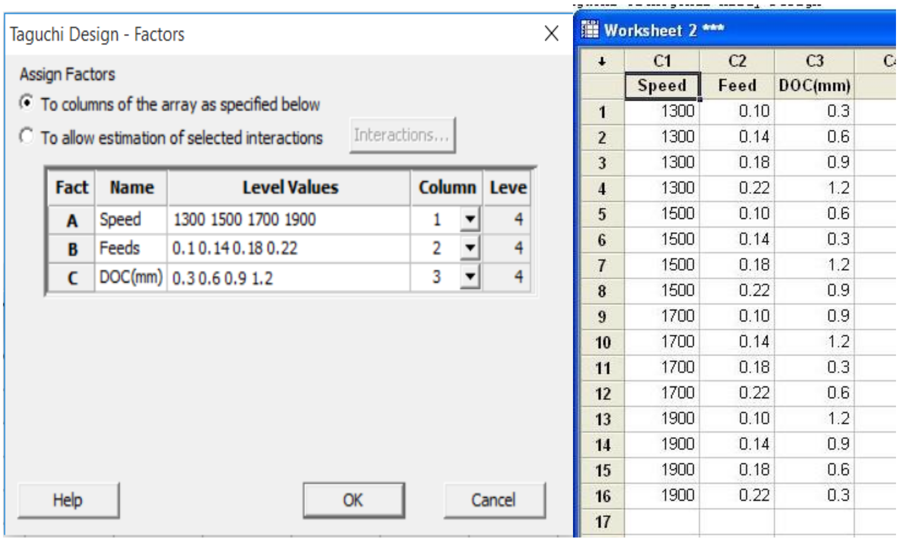


Figure 5.3. ***Taguchi 4 level design***





↓	C1 Speed	C2 Feed	C3 DOC(mm)
1	1300	0.10	0.3
2	1300	0.14	0.6
3	1300	0.18	0.9
4	1300	0.22	1.2
5	1500	0.10	0.6
6	1500	0.14	0.3
7	1500	0.18	1.2
8	1500	0.22	0.9
9	1700	0.10	0.9
10	1700	0.14	1.2
11	1700	0.18	0.3
12	1700	0.22	0.6
13	1900	0.10	1.2
14	1900	0.14	0.9
15	1900	0.18	0.6
16	1900	0.22	0.3
17			

Figure 5.4. Taguchi design factors

The three design factors levels feed, speed, the depth of cut are selected given in the above table.

5.3. Analysis of Variance (ANOVA)

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

ANOVA works on the means of variances of the response/SN ratios of the responses. ANOVA starts with the formulation of the hypothesis (like null hypothesis and alternate hypothesis) to be tested, followed by, and tests for the assumption about the normality of the data and the homogeneity of variance among the sets of the data. ANOVA formulates the hypothesis like null hypothesis (Ho) and alternate hypothesis (H1) as:

Ho: li = l for all i = 1, 2, 3 . . .

H1: li = l for some i = 1, 2, 3 . . .

Where li is the population mean for level i, and l is the overall grand mean of all levels.

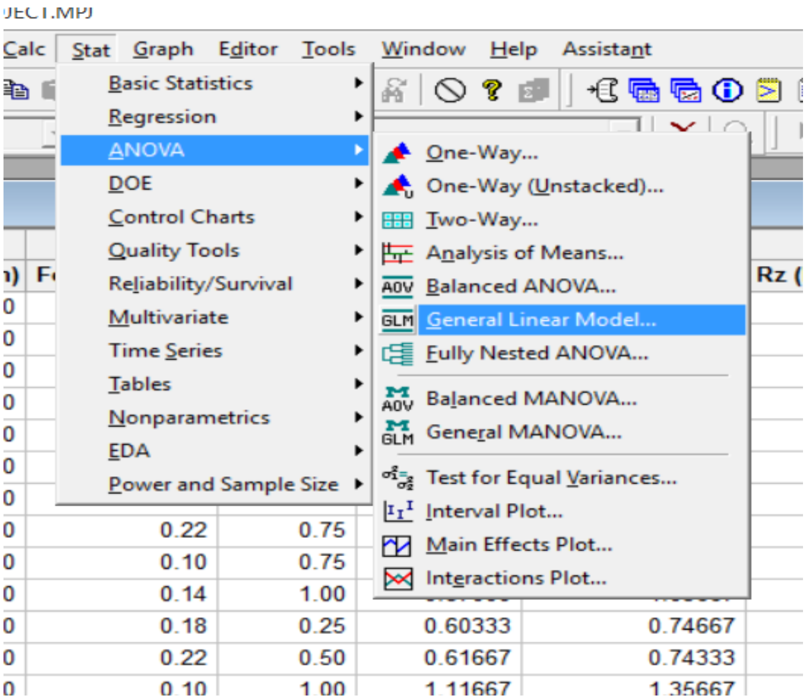


Figure 5.5. *ANOVA interactions*

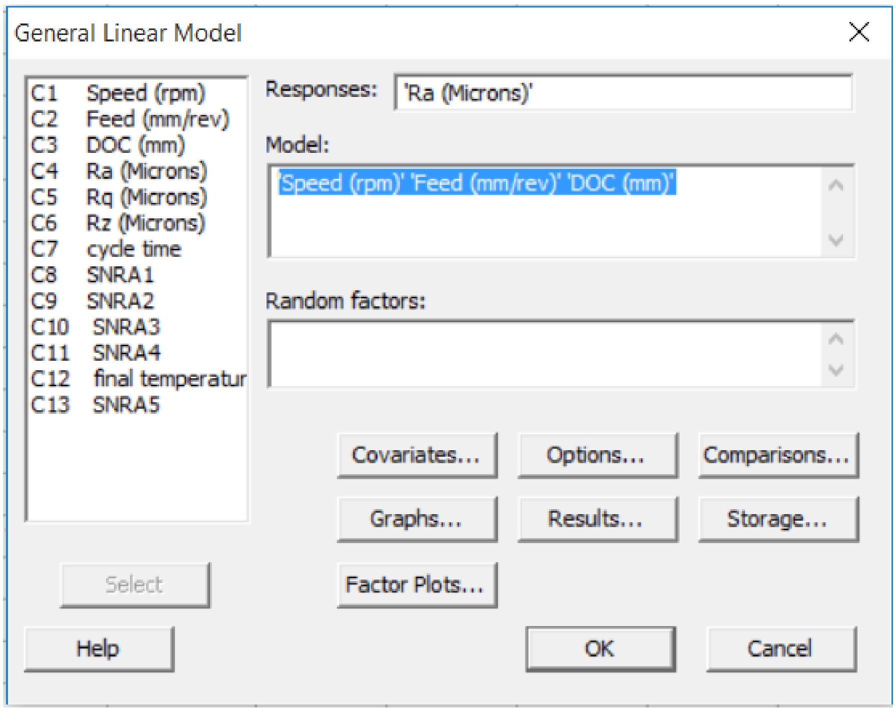


Figure 5.6. *Interaction responses and factors*

ANOVA assumes the null hypothesis to be correct until and unless, the alternate hypothesis is proved to be correct. To accept or reject null hypothesis, the F-statistical values are useful, like if

FSTATISTIC > FCRITICAL then reject null hypothesis.

ANOVA is carried on the generated responses to investigate the significant effect and indicate the contribution of design parameters on the quality characteristic of the response based on F-statistic test with significance level (a) of 95% (i.e. a < 0.05 probability) and uses.

ANOVA is used to investigate the significant effect of design parameters on the characteristic of the response. It also depicts the contribution of parameters on generating the required response. The statistical *F*-test is used to identify the significance of machining parameters.

Two-way ANOVA is used to determine the significances of the factors and their interaction using the following equations:

$$SS_{Total} \sum X^2 - \frac{(\sum X)^2}{N} \& DF = N - 1 \quad \text{.........................} (5.1)$$

$$SS_{Between} = \frac{(\sum X_1)^2}{n_1} + \frac{(\sum X_2)^2}{n_2} + \cdots + \frac{(\sum X_{AC})^2}{n_{AC}} - \frac{(\sum X)^2}{N} \quad \text{.........................} (5.2)$$

$$SS_C = \sum \frac{(\sum for\ each\ column)^2}{n\ for\ each\ column} - \frac{(\sum X)^2}{N} \quad \text{..........................} (5.3)$$

$$SS_C = \sum \frac{(\sum for\ each\ row)^2}{n\ for\ each\ row} - \frac{(\sum X)^2}{N} \quad \text{..........................} (5.4)$$

$$SS_{Within} = SS_{Total} - SS_{Between} \quad \text{..........................} (5.5)$$

$$\%Contribution = {}^{MS}/_{MS_{Total}} \quad \text{..........................} (5.6)$$

Where SS is sum of squares, MS is mean square, “DF” is degree of freedom, *N* is total observations, *and n* is size of population.

ANOVA is the statistical methodology for comparing group means and variation among and between groups. ANOVA compares “means” among groups based on the observed variance without assuming any parametric relationships. It uses the F-Statistic test which was developed by “Ronald Fisher”.

SOURCE	**DF**	**Sum of Squares (SS)**	**Mean Square (MS)**	**F_{OBS}**	**F_{CRI}**	**P**
Among or Between “Groups”	=(number of levels-1)	$SS_{Between}$	= (SS_{group})/DF_{group})	= (MSG/MSE)		
Within groups or “Error”	= (DF_{Total}- $DF_{groups\ total}$)	SS_{within}	= (SS_{Error})/DF_{Error})			
Total	= (N-1)	SS_{Total}				
R-Sq.						

$$SS_{Total} = \sum X^2 - \frac{\left(\sum X\right)^2}{N} \ \& \ DF = N - 1$$

$$SS_{Between} = \frac{\left(\sum X_1\right)^2}{n_1} + \frac{\left(\sum X_2\right)^2}{n_2} + ... - \frac{\left(\sum X\right)^2}{N}$$

SS_{Within}= SS_{Total} – $SS_{between}$ F-Calculated = F_{obs} = (MSG/MSE)

%Contribution = MS/MS_{Total} R-Sq. = (∑ “SS between Groups”)/ (∑ SS)

EXPERIMENTAL RECORDINGS AND CALCULATIONS

Chapter 6. EXPERIMENTAL RECORDINGS AND CALCULATIONS

Experimental design of L_{16} using Taguchi orthogonal array concept as shown in Table 1 is used for machining on AISI 316L workpiece. Each design was experimented using a new coated carbide insert tip for avoiding tool wear under dry conditions. Machining parameters viz. Spindle speed (N-1300, 1500, 1700, 1900 rpm), feed (f- 0.10, 0.14, 0.18, 0.22 mm /rev) and depth of cut (doc- 0.3, 0.6, 0.9, 1.2 mm) are considered for machining with four levels each. Responses like average surface roughness (R_a) and tool temperature (T) were measured using surface roughness tester and thermostat respectively, while the metal removal rate (MRR) was calculated theoretically, as given in Table 6.1.

6.1. EXPERIMENTAL RECORDINGS WHILE MACHINING

Table 6.1. Measured and calculated response values after machining

EXP. NO	Spindle Speed (N-rpm)	Feed (F-mm/rev)	Depth of cut (DOC-mm)	TOOL TEMPERATURE (Degree)	AVG. RA MICRONS)	MRR (mm^3/min)
1	1300	0.1	0.3	66	**0.723**	**3637**
2	1300	0.14	0.6	69	1.103	**10081**
3	1300	0.18	0.9	77	1.727	**19243**
4	1300	0.22	1.2	83	2.98	**31036**
5	1500	0.1	0.6	77	0.577	**8308**
6	1500	0.14	0.3	70	1.077	**5875**
7	1500	0.18	1.2	84	1.317	**29300**
8	1500	0.22	0.9	78	2.507	**27138**
9	1700	0.1	0.9	77	0.793	**13980**
10	1700	0.14	1.2	83	0.953	**25827**

11	1700	0.18	0.3	58	1.653	**8561**
12	1700	0.22	0.6	62	2.063	**20716**
13	1900	0.1	1.2	83	0.603	**20618**
14	1900	0.14	0.9	80	0.610	**21875**
15	1900	0.18	0.6	68	1.777	**18943**
16	1900	0.22	0.3	54	2.193	**11695**

6.2. SAMPLE CALCULATION OF Metal removal rate (MRR)

EXPERIMENT NO 1:

FORMULAE AND CALCULATION

MRR= 3.14*Davg * feed*DOC*speed

D_{avg} = average diameter of workpiece= (Di +D_F) /2

SPEED (N) =1300 rpm, FEED (F) =0.1 mm/rev, D_{avg}= 29.85 mm and depth of cut (DOC) = 0.3mm.

So, MRR = 3.14*29.85*0.1*0.3*1300 = 3637 mm^3/min

The obtained responses were used to analyse the significance of parameters using Analysis of variance (ANOVA) and also were used to evaluate multi-objective optimization criteria using numerical techniques like Grey relational analysis (GRA).

6.3. GREY RELATIONAL ANALYSIS (GRA)

GRA is a multi-response optimization technique which generates an optimal process parameter combination for all the responses generated by normalizing response values to make them comparable. Thereby determining the gray relation grade based on the deviation of normalized values and ranking the highest grade as optimal. It was proposed by Deng **[1-3]** and has been proven to be useful for dealing with the problems with poor, insufficient, and uncertain information.

Step 1: Normalization of experimental response data to convert into a sequence of comparable data using equation-4.1:

Response with low noise like surface finish and temperatures adopts;

Lower-is-Better (LB):
$$x_i^*(j) = \frac{[\max(x_i(j)) - x_i(j)]}{[\max(x_i(j)) - \min(x_i(j))]} \quad (6.1a)$$

Response with high noise like metal removal rate adopts;

Higher-is-Better (HB):
$$x_i^*(j) = \frac{[x_i(j) - \min(x_i(j))]}{[\max(x_i(j)) - \min(x_i(j))]} \quad (6.1b)$$

Where X_i (j) is the value of response of ith experiment, max (x_i (j)) and min (x_i (j)) are the smallest and largest values of X_i (j) respectively.

Sample calculation for surface roughness:

Experiment number 1:

For Normalization, Lower-is-Better (LB) and using the Eq: 6.1a, we get

For Lower-is-Better (LB):

$$x_i^*(j) = \frac{[\max(x_i(j)) - x_i(j)]}{[\max(x_i(j)) - \min(x_i(j))]} = [(2.98-0.723/ (2.98-0.577)] = 0.9392$$

Step 2: The deviation sequence $\Delta_{oi}(k)$ of each response given as:

$$\Delta_{oi}(k) = \|X_0(k) - X_i(k)\| \quad (6.2)$$

The deviation sequence using Eq: 6.2:

$$\Delta_{oi}(k) = \|X_0(k) - X_i(k)\| = |0.9392-1|= 0.0608$$

Step 3: Grey relational coefficient correlation between responses by giving equal weight age (distinguishable coefficient) as given in equation-6.3.

$$\gamma_i = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (6.3)$$

Where Δ_{min} is the smallest value of the normalized values, Δ_{max} is the maximum value of the normalized values, ζ is the distinguishing coefficient and ranges from 0 to 1 and has been assumed as 0.5 [4].

Grey relational coefficient is calculated using Eq: 6.3 and is given in Table 6.2a, as

$$\gamma_i = ((0+0.5*1)/ ((0.0608+ (0.5*1))) = 0.892$$

Step 4: Determination of grey relational grade of combined responses as given in Equation-4.4 and are graded as optimal with highest rank:

$$\alpha_i = \frac{1}{n}\sum_{k=1}^{n} \gamma_i(k) \qquad (6.4)$$

Where "n_r" is the total number of responses

Based on the grey relational grade, the ranking has to be given in descending order. The combination of process parameters which has the highest rank is considered to be optimal, as given in Table 6.2a. Grey relational grade using Equation-6.4 and are graded as optimal with highest rank:

$$\alpha_1 = \frac{(0.892 + 0.333 + 0.556)}{3} = 0.594$$

Table 6.2. ***Normalization, Grey relational coefficient for determining grey relational grade and ranking***

Exp. No.	**Normalization based on LB/HB**			**Grey Relational Coefficients**			**Grey Relational Grade**	**Rank**
	Ra (µm)	**MRR (mm^3/ min)**	**Temp (Degree)**	**Ra (µm)**	**MRR (mm^3/ min)**	**Temp (Degree)**		
1	0.9392	0.0000	0.6000	0.892	0.333	0.556	0.594	
2	0.7811	0.2352	0.5000	0.696	0.395	0.500	0.530	
3	0.5214	0.5696	0.2333	0.511	0.537	0.395	0.481	
4	0.0000	1.0000	0.0333	0.333	1.000	0.341	0.558	
5	1.0000	0.1705	0.2333	1.000	0.376	0.395	0.590	
6	0.7919	0.0817	0.4667	0.706	0.353	0.484	0.514	
7	0.6921	0.9366	0.0000	0.619	0.888	0.333	0.613	
8	0.1968	0.8577	0.2000	0.384	0.778	0.385	0.516	
9	0.9101	0.3775	0.2333	0.848	0.445	0.395	0.563	
10	0.8435	0.8099	0.0333	0.762	0.725	0.341	0.609	
11	0.5522	0.1797	0.8667	0.528	0.379	0.789	0.565	

12	0.3816	0.6233	0.7333	0.447	0.570	0.652	0.557	
13	0.9892	0.6198	0.0333	0.979	0.568	0.341	0.629	
14	**0.9863**	**0.6656**	**0.1333**	**0.973**	**0.599**	**0.366**	**0.646**	**1**
15	0.5006	0.5586	0.5333	0.500	0.531	0.517	0.516	
16	0.3275	0.2941	1.0000	0.426	0.415	1.000	0.614	

6.4. ANOVA FOR DRY CONDITION MACHINING

Analysis of variance (ANOVA) is a statistical model based on hypothesis of accepting or rejecting null hypothesis, by analysing the difference between groups and among the groups. Based on relation between $F_{statistical}$ and $F_{critical}$ the acceptance and rejection of hypothesis is done. The ANOVA uses equations: 6.9-6.12 to determine significance and indicates the contribution of design parameters on the quality characteristic of the response with significance level of 95% (i.e. < 0.05 probability) [7] and are shown in Table 6.3.

$$SS_{Total} = \sum X^2 - \frac{(\sum X)^2}{N} \quad \text{and} \quad DF = N - 1 \tag{6.5}$$

$$SS_{Between} = \frac{(\sum [X_1)]^2}{n_1} + \frac{([\sum X_2)]^2}{n_2} + \cdots + \frac{([\sum X_{AC})]^2}{n_{AC}} - \frac{(\sum [X)]^2}{N} \tag{6.6}$$

$$SS_{Within} = SS_{Total} - SS_{Between} \tag{6.7}$$

Where SS is the sum of squares, MS is the mean square, “DF” is the degree of freedom, *N* is the total observations, *and the* size of population.

Table 6.3. ANOVA of experimental responses data

Source	DF	SS	MS	F	P	Remarks
Surface roughness (R_a) (F-Critical of 3,6 is 4.757)						
Speed (rpm)	3	10.5	3.45	1.02	0.446	Not significant (NS)
Feed (mm/rev)	3	294.60	98.2	29.14	0.001	Highly significant (HS)
d (mm)	3	00.981	0.33	0.10	0.959	Not significant (NS)
Error	6	20.21	3.36			
Tool temperature (Temp)						
Speed (rpm)	3	2.12	0.707	5.47	0.037	S
Feed (mm/rev)	3	2.14	0.714	5.53	0.037	S
d (mm)	3	16.09	5.365	41.5	0.000	HS
Error	6					
Metal removal rate (MRR)						
Speed (rpm)	3	24.17	8.05	143248	0.000	HS
Feed (mm/rev)	3	104.72	34.90	620656	0.000	HS
d (mm)	3	313.23	104.4	185641	0.000	HS
Error	6					

RESULTS, DISCUSSIONS AND CONCLUSIONS

Chapter 7. RESULTS, DISCUSSIONS AND CONCLUSIONS

Observing Table 6.2a, *using* ***GRA***, the optimality obtained is Spindle speed: 1900 rpm, feed: 0.14 mm/rev and depth of cut: 0.9 mm which generates surface roughness (R_a = 0.610 µm), Tool temperature (Temp = 80^0C) and metal removal rate (MRR = 21875 mm^3 /min). Similarly, observing Table 6.2c, Spindle speed: 1500 rpm, feed: 0.18 mm/rev and depth of cut: 1.2 mm which generates surface roughness (R_a = 1.317 µm), Tool temperature (Temp = 84^0C) and metal removal rate (MRR = 29300 mm^3 /min). The GRA method generates better results in case of roughness and temperature, but not in case of Metal removal rate. But if given due weightage of responses are incorporated in GRA.

Based on ANOVA for finding significance of machining parameters, graph plots are drawn between responses and major contributing parameters. As shown in fig. 2 feed indicates much more effect than spindle speed while generating roughness and similarly, depth of cut on tool temperatures and MRR.

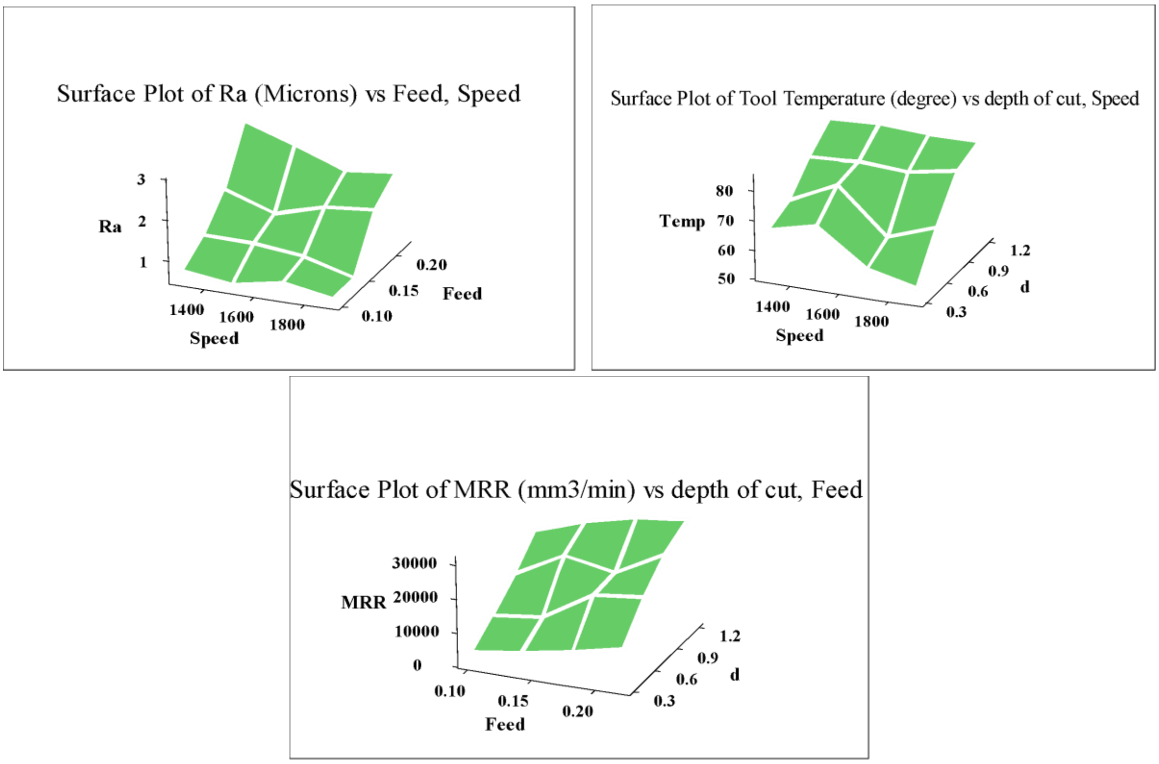


Figure 7.1. Graph plots of the results obtained from TDOE

CONCLUSIONS

- The chips generated in machining are found to be of helix in nature and at higher depth of cuts, they break into long helical chips due to weight.
- Discontinuous small helical chips were produced at low feeds and depth of cut, while at moderate feed and depth of cuts, helical chips whirled around the workpiece from the middle of the machining.
- Analysing ANOVA of the machining parameters on the generated responses: feed alone constitutes for generating surface roughness, while all the parameters contributes significantly but depth of cut contributes more significantly in generating tool temperatures due to penetration of tool into workpiece and in case of metal removal rate all the parameters are highly significant in its generation.

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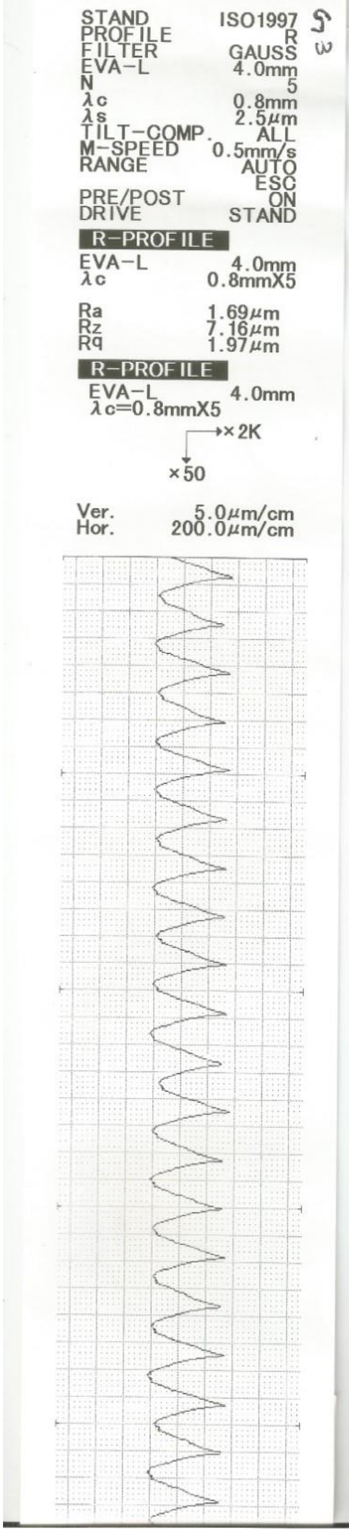
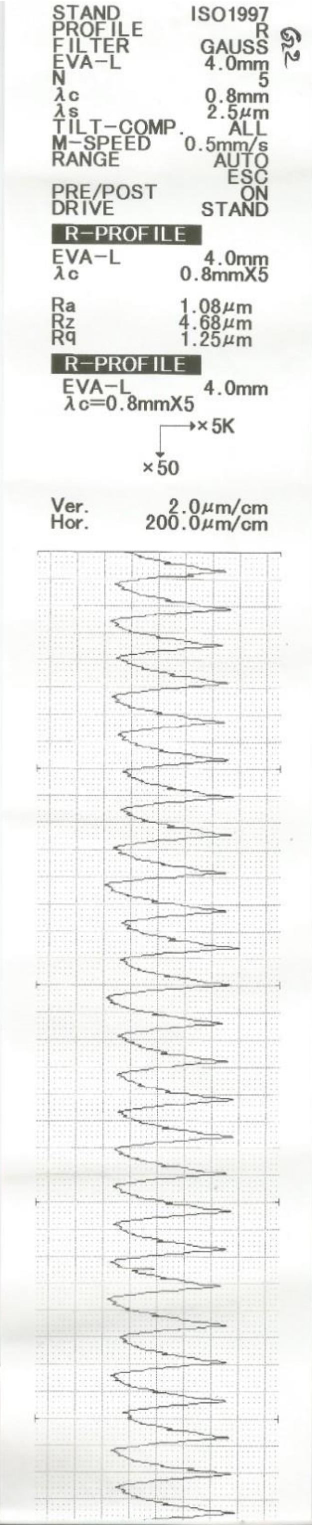
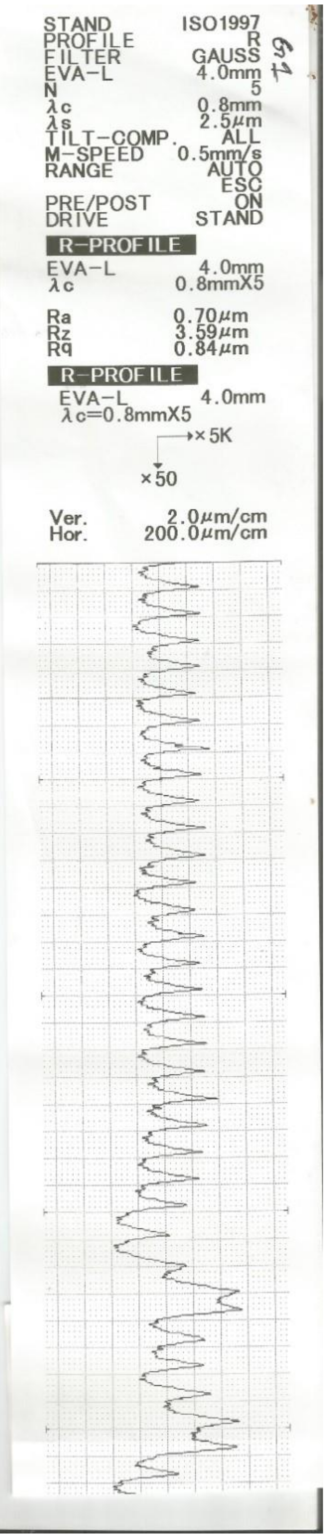
APPENDIX-A

(SURFACE ROUGHNESS PROFILES)







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UGC Approved Journal no 63975
ISSN: 2349-5162 | ESTD Year : 2014
Call for Paper
Volume 8 | Issue 6 | June 2021

...ed in:
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...and ISSN approved 7.95 impact factor UGC Approved Journal no 63975

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Title

OPTIMIZATION OF MACHINING PARAMETERS ON CNC LATHE AISI 316L MATERIAL WITH COATED CARBIDE INSERTS USING TAGUCHI GRA METHODS

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Key Words

GRA, TAGUCHI, MRR, DOE

Cite This Article

"OPTIMIZATION OF MACHINING PARAMETERS ON CNC LATHE AISI 316L MATERIAL WITH COATED CARBIDE INSERTS USING TAGUCHI GRA METHODS", International Journal of Emerging Technologies and Innovative Research (www.jetir.org), ISSN:2349-5162, Vol.8, Issue 6, page no.e496-e502, June-2021, Available :http://www.jetir.org/papers/JETIR2106625.pdf

ISSN

2349-5162 | Impact Factor 7.95 Calculate by Google Scholar

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Unique Identifier

Published Paper ID: JETIR2106625

Registration ID: 311314

Page Number

e496-e502

Post-Publication

https://www.jetir.org/view?paper=JETIR2106625

Publication Details

Published Paper ID: JETIR2106625

Registration ID: 311314

Published In: Volume 8 | Issue 6 | Year June-2021

DOI (Digital Object Identifier):

Page No: e496-e502

Country: visakhapatnam, Andhra Pradesh, India .

Area: Engineering

ISSN Number: 2349-5162

Published Paper URL :: https://www.jetir.org/view?paper=JETIR2106625

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***IndexTerms* – GRA, TAGUCHI, MRR, DOE**

I. INTRODUCTION

1.1 Lathe

A rotating machine tool is a workpiece that rotates around an axis of rotation to perform various tasks, such as cutting, sanding, kneeling, drilling, deformation, facing and turning, with tools on the workpiece to build an object with symmetry on that axis.

1.1.1Lathe Components

- Bed: all main components are supported
- Transportation: slides along paths, consisting of slide cross, tool, apron
- Headstock: holds jaws for the workpiece, provides electricity to the jaws and has different drive speeds
- Tail Stock - supports the workpiece's other end
- Lead Screw and feed rod – Feed rod is powered from the headstock by a set of gears

The lathe played a crucial role in the Industrial Revolution.By rotating the work piece against a stationary cutting tool, the lathe removes superfluous material in the form of chips. The lathe is a machine tool that rotates and holds the work item between two rigid and strong supports known as centers, a chuck, or a face plate. The cutting tool is held against the rotating work and fed into it. Cutting tool fed parallel, at right angles, or at an angle to the axis of the workpiece.

1.2. CNC Machining

CNC machines, or computer numerically controlled machines, are electro-mechanical devices which will manipulate tools around a varying number of axis, usually 3 or 5, with high-precision per instruction from a bug. CNC machining is one in every of two ways in which engineers, machinists, or makers can generate a physical part from a computer design file, with the opposite being 3D printing, called additive manufacturing.

CNC machines can be used to machine almost any material. Metals (aluminium and steel alloys, brass, etc.) and plastics are two of the most common examples (ABS, Delrin, Nylon etc.). Machines can also be used to cut foam, composites, and wood. The essential CNC process will be reduced to three steps. The engineer begins by creating a CAD model of the part. The machinists then convert the CAD file to a CNC programme (G-code) and set up the machine. Finally, the CNC system performs all machining operations, removing material and creating the part, with little supervision.

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I. INTRODUCTION

1.1 Lathe

A rotating machine tool is a workpiece that rotates around an axis of rotation to perform various tasks, such as cutting, sanding, kneeling, drilling, deformation, facing and turning, with tools on the workpiece to build an object with symmetry on that axis.

1.1.1Lathe Components

- Bed: all main components are supported
- Transportation: slides along paths, consisting of slide cross, tool, apron
- Headstock: holds jaws for the workpiece, provides electricity to the jaws and has different drive speeds
- Tail Stock - supports the workpiece's other end
- Lead Screw and feed rod – Feed rod is powered from the headstock by a set of gears

The lathe played a crucial role in the Industrial Revolution.By rotating the work piece against a stationary cutting tool, the lathe removes superfluous material in the form of chips. The lathe is a machine tool that rotates and holds the work item between two rigid and strong supports known as centers, a chuck, or a face plate. The cutting tool is held against the rotating work and fed into it. Cutting tool fed parallel, at right angles, or at an angle to the axis of the workpiece.

1.2. CNC Machining

CNC machines, or computer numerically controlled machines, are electro-mechanical devices which will manipulate tools around a varying number of axis, usually 3 or 5, with high-precision per instruction from a bug. CNC machining is one in every of two ways in which engineers, machinists, or makers can generate a physical part from a computer design file, with the opposite being 3D printing, called additive manufacturing.

CNC machines can be used to machine almost any material. Metals (aluminium and steel alloys, brass, etc.) and plastics are two of the most common examples (ABS, Delrin, Nylon etc.). Machines can also be used to cut foam, composites, and wood. The essential CNC process will be reduced to three steps. The engineer begins by creating a CAD model of the part. The machinists then convert the CAD file to a CNC programme (G-code) and set up the machine. Finally, the CNC system performs all machining operations, removing material and creating the part, with little supervision.

Fig.2 CNC Lathe

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1.3. INTRODUCTION TO TAGUCHI

Design of Experiment

In general, the design or experimental design is the design of any data collection exercise in which there are differences, whether or not under the complete control of an experiment.These terms are, however, usually used for checked experiments in statistics. Previous planned tests are often used for physical objects, chemical formulations, structures, components and materials.The paper on opinion surveys and statistical surveys, natural experiments and quasi-experiments (i.e., quasi-experimental design) see experiments on how these types of experiments or studies are differentiated between these kinds of experiments and design, are discussed in other types of survey.

II. LITERATURE REVIEW

A proper selection of cutting conditions in CNC machining processes such as turning produces high surface finish and less dimensional error parts subject to fatigue loads, precision fits, and aesthetic requirements. As a result, many researchers concentrate on the literature on the measurement of surface roughness using (lathe) and multi-point (milling) cutting tools with various machining parameters such as feed, speeds, depth of cut, and tool geometry. The research in this field can be divided into four categories:

- Trends derived from machining theories
- Trends derived from experimental tests
- Trends derived from designed tests (TAGUCHI based)
- Trends derived from intelligent neutral networks

Ali Motorcu Riza [1] studied the surface roughness in the turning of A181 8660 hardened alloy steels by ceramic based cutting tools with cutting parameters such as cutting speed, depth of cut, feed rate in addition tool's nose radius, using a statistical approach An orthogonal design, signal-to noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness.

W.H. Yang, and Y.S. Tarng [2] investigated the cutting characteristics of 854C steel bars using tungsten carbide cutting tools using the Taguchi method, which was studied as a powerful tool for quality design and used to find the optimal cutting parameters for turning operations based on orthogonal array, signal-to-noise (S/N) ratio, and analysis of variance (ANOVA). They discovered not only the optimal cutting parameters for cutting operations, but also the main cutting parameters that affect cutting performance in turning operations, through this study. The experimental results are provided to validate the efficacy of this approach.

Dilbag Singh et al. [4] The effect of cutting and tool geometry on surface roughness was investigated with a mixed ceramic insert made from aluminium oxide and titanium carbon nitride, using the hardened turning of bearing steel (AISI 52100). This study showed that feed is the dominating determination factor for the finish of the surface; the cuts are followed by a cutting velocity and the rake angle of the tool.

RA Mahdavinejad et al.[5] have highlighted surface-roughness methods for predicting process theory trends based on designed laboratory tests based on laboratory research like neutral networks, GA, Fuzzy, etc. The combination of the Neutral Fuzzy adaptive system predicts the roughness of the dried surface, which is machined during turning.

C.X. (Jack) Feng etal. [6] has developed a non-linear regression surface prediction model for surface roughness, based on work-piece hardness (material) cutting parameters, geometry of tools and cutting time, and its applications in order to determine the optimum conditions of machining.

A. Manna. [7] In a study of how the cutting conditions affect surface finishes, Pujari Srinivasa [8] Rao has been using Taguchi to optimize the cutting parameters for efficiency of turning with Al/Sic-MMC with fixed rhombic systems. Important parameters of cutting have been taken into account and mathematical models for surface roughness Ra and Rt have been developed using multiple lineal regression.

Grey relational analysis (GRA) depends on the response values generated for the problem under consideration (here machining responses like Ra, H and Vib in both the turn-mill processes) and determine the combined optimal combination of process parameters with only the set of process parameters levels considered. GRA first converts the response values which are incomparable to each other to comparable values using the concept of normalizing using larger-to-better or smaller-is-better equations. Then the converted and comparable response data are used to determine process parameters combination of the multi-response (I.e. Ra, H and Vib) [9-12].

III. EXPERIMENTATION METHODOLOGY

3.1Workpiece Material and Cutting Tool

Stainless steels are resistant to corrosion and contain at least 0.10% chromium. The hardness of infinite steels with austenitic structures is not a speed guide. American Institute of Iron and Steel (AISI) grade 316L is similar to AISI 316L but contains an additional component like molybdenum that improves creep strength, warmth, and resistance against corrosion, wear and hardness. The AISI 316L chemical composition includes Cr 17.5% C 0.06%, Mn 1.5%, Ni 12.2%, Mo 2.5%, Si 0.75% and Fe remaining, respectively. The chemical composition includes: Fig.4.1 shows workpiece materials of a diameter of 30 mm and a length of 100 mm. For the recording of tool temperature, the K-type protected thermocouple was used, while the surface roughness test MITUTOYO is used for measuring surface-ruggedness parameters as shown in fig. 3. In addition, the CNMG120408 MS KC 5010 covered carbide inserts are used for processing ACE micro CNC laths with the Fanuc 0i control system shown in fig.4.Coated carbide tool has excellent mechanical and thermal shock resistance. This gives good adherence to a high crater wear resistance and high-temperature plastic deformation. It also reduces friction and thus build-up edges.

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Fig.4 AISI 316L workpiece after machining and surface roughness tester SJ-301

Fig.5 CNC lathe with Fanuc-0i control system and coated carbide inserts

3.2. Process of Machining

Workpiece length of 100mm each and then using the Taguchi design of experiments test conditions were generated by taking feed, cutting speed and depth of cut as parameters. As the surface area is cylindrical, surface roughness is determined by three diametric points and the average is considered to be the material's surface roughness.

In this project, 16 turning experiments were done on the CNC lathe and the surface roughness readings, tool tip temperature and MRR were measured using surface roughness tester and thermostat respectively, while MRR was calculated theoretically. The responses were made by using commercially available data mining technology software packages such as MINITAB software to find the parameter significance using Variance Analysis (ANOVA).

3.3. Process parameters

The characteristic parameters of a turning operation are (example: straight turning of cylinder with a diameter d (in mm)), Cutting Parameters:

- The depth of cut-DOC (mm)
- The feed per rotation-f (mm/rev)

The cutting speed $\mathbf{v_c}$ in (m/min) which gives the rotational speed N (rpm)

N= (1000*v_c/3.14*D)

The cutting parameters are at the root of the following performance parameters:

The material removal rate Q (cm^3/min): Q=d*f*V_c

N= rotational speed of the workpiece, RPM

f= feed, mm/rev

V= surface speed of the workpiece, m/min = 3.14*D_o*N (for max speed)

L=length of the cut, mm

D_o = original diameter of the workpiece, mm

D_f = final diameter of the workpiece, mm

D_{avg} = average diameter of workpiece= (Di+D_F)/2

DOC= depth of cut, mm

C_t = cutting time, s

MRR= 3.14*Davg* feed*DOC*speed.

3.4 Procedure

- Insert a new coated carbide tool insert.
- Start machining of the workpiece with the test conditions that were obtained from Taguchi Design of experiments.
- Before the process of machining insert the thermocouple at the tool tip of CNC and ensure that the offset of the tool is set properly.
- Once the machining for each test conditions is completed surface roughness was tested with MITUTOYO tester, Tool temperature using Thermocouple and material removal rate is calculated.
- ANOVA was done for surface roughness, temperature and material removal rate.
- Multi-response optimizations response done using GRA.

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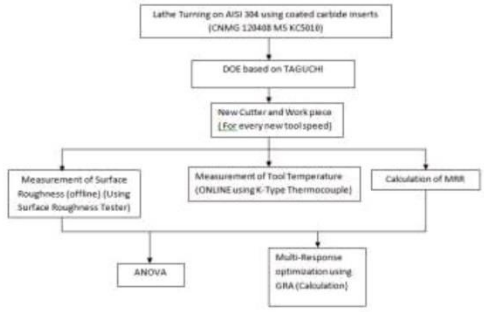


Fig.6 Experimental Methodology

IV. EXPERIMENTAL RECORDINGS AND CALCULATIONS

Experimental design of L_{16} using Taguchi orthogonal array concept as shown in Table 1 is used for machining on AISI 316L workpiece. Each design was experimented using a new coated carbide insert tip for avoiding tool wear under dry conditions. Machining parameters viz. Spindle speed (N-1300, 1500, 1700, 1900 rpm), feed (f- 0.10, 0.14, 0.18, 0.22 mm /rev) and depth of cut (doc- 0.3, 0.6, 0.9, 1.2 mm) are considered for machining with four levels each. Responses like average surface roughness (R_a) and tool temperature (T) were measured using surface roughness tester and thermostat respectively, while the metal removal rate (MRR) was calculated theoretically, as given in Table 1.

4.1 SAMPLE CALCULATION OF Metal removal rate (MRR)

EXPERIMENT NO 1:

FORMULAE AND CALCULATION

MRR= 3.14*Davg* feed*DOC*speed

D_{avg} = average diameter of workpiece= $(Di+D_F)/2$

SPEED (N) =1300 rpm, FEED (F) =0.1 mm/rev, D_{avg}= 29.85 mm and depth of cut (DOC)= 0.3mm.

So, MRR = 3.14*29.85*0.1*0.3*1300 = **3637** mm^3/min

The obtained responses were used to analyse the significance of parameters using Analysis of variance (ANOVA) and also were used to evaluate multi-objective optimization criteria using numerical techniques like Grey relational analysis (GRA).

Table 1: Measured and calculated response values after machining

EXP. NO	Spindle Speed (N-rpm)	Feed (F-mm/rev)	Depth of cut (DOC-mm)	TOOL TEMPERATURE (Degree)	AVG. RA MICRONS)	MRR (mm^3/min)
1	1300	0.1	0.3	66	**0.723**	**3637**
2	1300	0.14	0.6	69	1.103	**10081**
3	1300	0.18	0.9	77	1.727	**19243**
4	1300	0.22	1.2	83	2.98	**31036**
5	1500	0.1	0.6	77	0.577	**8308**
6	1500	0.14	0.3	70	1.077	**5875**
7	1500	0.18	1.2	84	1.317	**29300**
8	1500	0.22	0.9	78	2.507	**27138**
9	1700	0.1	0.9	77	0.793	**13980**
10	1700	0.14	1.2	83	0.953	**25827**
11	1700	0.18	0.3	58	1.653	**8561**
12	1700	0.22	0.6	62	2.063	**20716**
13	1900	0.1	1.2	83	0.603	**20618**
14	1900	0.14	0.9	80	0.610	**21875**
15	1900	0.18	0.6	68	1.777	**18943**
16	1900	0.22	0.3	54	2.193	**11695**

4.2. GREY RELATIONAL ANALYSIS (GRA)

Sample calculation for surface roughness:

Experiment number 1:

Step 1: Normalization of experimental response data to convert into a sequence of comparable data using equation-4.1:

Response with low noise like surface finish and temperatures adopts;

Lower-is-Better (LB):

$$x_i^*(j) = \frac{[max(x_i(j)) - x_i(j)]}{[max(x_i(j)) - min(x_i(j))]} \quad (4.1a)$$

Response with high noise like metal removal rate adopts;

Higher-is-Better (HB):

$$x_i^*(j) = \frac{[x_i(j) - \min(x_i(j))]}{[\max(x_i(j)) - \min(x_i(j))]} \quad (4.1b)$$

Where X_i (j) is the value of response of i[th] experiment, max (x_i (j)) and min (x_i (j)) are the smallest and largest values of X_i (j) respectively.

For Normalization, Lower-is-Better (LB) and using the Eq: 6.1a, we get

For Lower-is-Better (LB): $x_i^*(j) = \frac{[\max(x_i(j)) - x_i(j)]}{[\max(x_i(j)) - \min(x_i(j))]}$ = [(2.98-0.723/ (2.98-0.577)] = 0.9392

Step 2: The deviation sequence $\Delta_{oi}(k)$ of each response given as:

$$\Delta_{oi}(k) = ||X_0(k) - X_1(k)|| \quad (4.2)$$

The deviation sequence using Eq: 4.2: $\Delta_{oi}(k) = ||X_0(k) - X_1(k)||$= |0.9392-1|= 0.0608

Step 3: Grey relational coefficient correlation between responses by giving equal weight age (distinguishable coefficient) as given in equation-4.3.

$$\gamma_i = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (4.3)$$

Where Δ_{min} is the smallest value of the normalized values, Δ_{max} is the maximum value of the normalized values, ζ is the distinguishing coefficient and ranges from 0 to 1 and has been assumed as 0.5.

Grey relational coefficient is calculated using Eq: 4.3 and is given in Table 2, as $\gamma_i = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}}$

= ((0+0.5*1)/((0.0608+(0.5*1)))= 0.892

Step 4: Determination of grey relational grade of combined responses as given in Equation-4.4 and are graded as optimal with highest rank:

$$\alpha_i = \sum_{k=1}^{n} \gamma_i(k) \quad (6.4)$$

Where "n_r" is the total number of responses

Based on the grey relational grade, the ranking has to be given in descending order. The combination of process parameters which has the highest rank is considered to be optimal, as given in Table 6.2a. Grey relational grade using Equation-6.4 and are graded as optimal with highest rank: $\alpha_i = \frac{(0.892+0.333+0.556)}{3}$ = 0.594

Table 2: Normalization, Grey relational coefficient for determining grey relational grade and ranking

Exp. No.	Normalization based on LB/HB			Grey Relational Coefficients			Grey Relational Grade	Rank
	Ra (μm)	MRR (mm³/min)	Temp (Degree)	Ra (μm)	MRR (mm³/min)	Temp (Degree)		
1	0.9392	0.0000	0.6000	0.892	0.333	0.556	0.594	
2	0.7811	0.2352	0.5000	0.696	0.395	0.500	0.530	
3	0.5214	0.5696	0.2333	0.511	0.537	0.395	0.481	
4	0.0000	1.0000	0.0333	0.333	1.000	0.341	0.558	
5	1.0000	0.1705	0.2333	1.000	0.376	0.395	0.590	
6	0.7919	0.0817	0.4667	0.706	0.353	0.484	0.514	
7	0.6921	0.9366	0.0000	0.619	0.888	0.333	0.613	
8	0.1968	0.8577	0.2000	0.384	0.778	0.385	0.516	
9	0.9101	0.3775	0.2333	0.848	0.445	0.395	0.563	
10	0.8435	0.8099	0.0333	0.762	0.725	0.341	0.609	
11	0.5522	0.1797	0.8667	0.528	0.379	0.789	0.565	
12	0.3816	0.6233	0.7333	0.447	0.570	0.652	0.557	
13	0.9892	0.6198	0.0333	0.979	0.568	0.341	0.629	
14	**0.9863**	**0.6656**	**0.1333**	**0.973**	**0.599**	**0.366**	**0.646**	**1**
15	0.5006	0.5586	0.5333	0.500	0.531	0.517	0.516	
16	0.3275	0.2941	1.0000	0.426	0.415	1.000	0.614	

4.3 ANOVA FOR DRY CONDITION MACHINING

Analysis of variance (ANOVA) is a statistical model based on hypothesis of accepting or rejecting null hypothesis, by analysing the difference between groups and among the groups. Based on relation between $F_{statistical}$ and $F_{critical}$ the acceptance and rejection of hypothesis is done. The ANOVA uses equations: 6.5-6.7 to determine significance and indicates the contribution of design parameters on the quality characteristic of the response with significance level of 95% (i.e. < 0.05 probability) [7] and are shown in Table 3.

$$SS_{Total} = \sum X^2 - \frac{(\sum X)^2}{N} \text{ and } DF = N - 1 \quad (6.5)$$

$$SS_{Between} = \frac{[\sum(X_1)]^2}{n_1} + \frac{[\sum(X_2)]^2}{n_2} + \cdots + \frac{[\sum(X_{AC})]^2}{n_{AC}} - \frac{[\sum X)]^2}{N} \quad (6.6)$$

$$SS_{Within} = SS_{Total} - SS_{Between} \quad (6.7)$$

Where SS is the sum of squares, MS is the mean square, "DF" is the degree of freedom, *N* is the total observations, *and the* size of population.

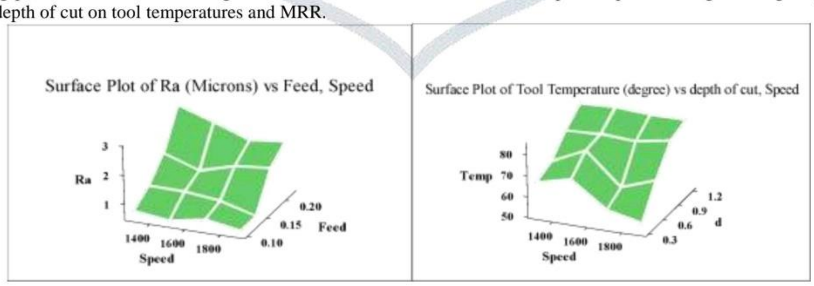
Table 3: ANOVA of experimental responses data

Source	DF	SS	MS	F	P	Remarks
Surface roughness (R_a) (F-Critical of 3,6 is 4.757)						
Speed (rpm)	3	10.5	3.45	1.02	0.446	Not significant (NS)
Feed (mm/rev)	3	294.60	98.2	29.14	0.001	Highly significant (HS)
d (mm)	3	00.981	0.33	0.10	0.959	Not significant (NS)
Error	6	20.21	3.36			
Tool temperature (Temp)						
Speed (rpm)	3	2.12	0.707	5.47	0.037	S
Feed (mm/rev)	3	2.14	0.714	5.53	0.037	S
d (mm)	3	16.09	5.365	41.5	0.000	HS
Error	6					
Metal removal rate (MRR)						
Speed (rpm)	3	24.17	8.05	143248	0.000	HS
Feed (mm/rev)	3	104.72	34.90	620656	0.000	HS
d (mm)	3	313.23	104.4	185641	0.000	HS
Error	6					

V. Results, Discussions And Conclusions

Observing Table 2, using GRA, the optimality obtained is Spindle speed: 1900 rpm, feed: 0.14 mm/rev and depth of cut: 0.9 mm which generates surface roughness (Ra = 0.610 µm), Tool temperature (Temp = 800C) and metal removal rate (MRR = 21875 mm3 /min). Similarly, observing Table 6.2c, Spindle speed: 1500 rpm, feed: 0.18 mm/rev and depth of cut: 1.2 mm which generates surface roughness (Ra = 1.317 µm), Tool temperature (Temp = 840C) and metal removal rate (MRR = 29300 mm3 /min). The GRA method generates better results in case of roughness and temperature, but not in case of Metal removal rate. But if given due weightage of responses are incorporated in GRA.

Based on ANOVA for finding significance of machining parameters, graph plots are drawn between responses and major contributing parameters. As shown in fig. 2 feed indicates much more effect than spindle speed while generating roughness and similarly, depth of cut on tool temperatures and MRR.



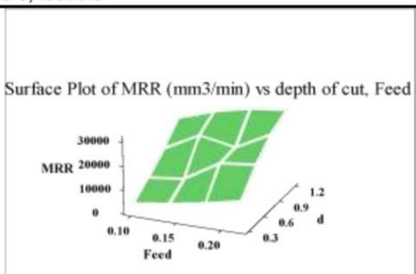


Fig.7 Graph plots of the results obtained from TDOE

Conclusions

- The chips generated in machining are found to be of helix in nature and at higher depth of cuts, they break into long helical chips due to weight.
- Discontinuous small helical chips were produced at low feeds and depth of cut, while at moderate feed and depth of cuts, helical chips whirled around the workpiece from the middle of the machining.
- ANOVA of the machining parameters on the generated responses: feed alone constitutes for generating surface roughness, while all the parameters contributes significantly but depth of cut contributes more significantly in generating tool temperatures due to penetration of tool into workpiece and in case of metal removal rate all the parameters are highly significant in its generation.

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