APPLICATION OF DESIRABILITY-GREY ANALYSIS FOR THE OPTIMIZATION OF SS304 RESPONSES

A project report submitted in partial fulfilment of the requirement for

the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

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Sangivalasa, Bheemunipatnam Mandal
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(2017- 2021)

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CERTIFICATE

This is to certify that the Project Report entitled "**APPLICATION OF DESIRABILITY GREY ANALYSIS FOR THE OPTIMIZATION OF SS304 RESPONSES**" being submitted by POOTHI VENU SATYA JAYA RAJU REDDY (318126520L09), MUGADA RAHUL (317126520034), UPPALA HARESH (317126520054), VENKATA GANGA SAI LAVANYA (317126520058), VANAPALLI TEJESH (317126520056) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **DR. V. BINDU NEEHARIKA**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

PROJECT GUIDE

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ABSTRACT

The present work is to study the effect of cutting parameters on the multiple performance characteristics in dry turning of SS304 steel. The work material considered is good in processability, weldability, corrosion resistance, heat resistance etc. Because of its properties it has applications in petroleum & chemical industry, metallurgical machinery, aerospace industry, food processing equipment’s, household appliances and hardware manufacturing industries. A series of experiments were designed and performed with coated tungsten carbide tools on CNC turret lathe. Taguchi’s mixed L18 orthogonal array is employed for the selected process parameters. The multiple responses of material removal rate (MRR) and surface roughness (R_a) were explored using taguchi based desirability grey analysis. The results predicted that the feed is the most influencing factor and the model prepared is best fit and adequate.

Keywords: SS304, Material Removal Rate (MRR), Surface Roughness (R_a), Desirability-Grey analysis.

CHAPTER--1
INTRODUCTION

Turing is the machining operation that produces cylindrical parts. In its basic from, it can be defined as the machining of external surfaces:

- With the workpiece rotating
- With a single-point cutting tool
- With the cutting tool feeling parallel to the axis of the workpiece and at a distance that will remove the outer surface of the work.

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setup, which is often employed in turning. In such setups, each tool operates independently as a single-point cutter.

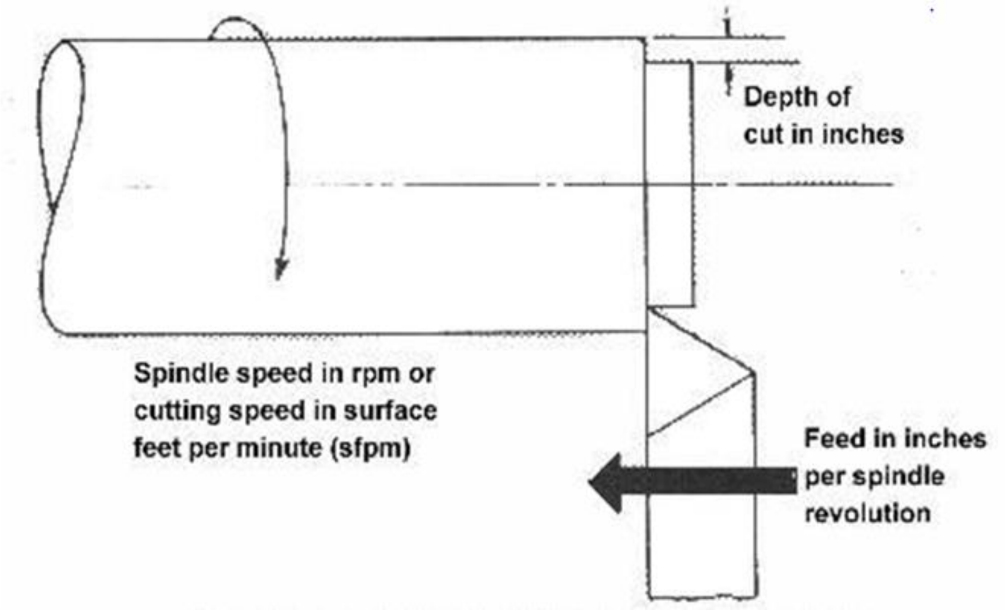

Figure.1 Turning Operation

Lathe Machine Operations:

The machine operations are classified into three main categories and are as follows.
Following are the lathe machine operations done either by holding the workpiece between centers or by a chuck:

- ➢ Turning operation
- ▪ Plain or straight turning
- ▪ Rough turning
- ▪ Shoulder turning
- ▪ Taper turning

- Eccentric turning
- Facing operation
- Chamfering operation
- Knurling operation
- Thread cutting operation
- filing operation
- Polishing operation
- Grooving operation
- Spinning operation
- Spring winding
- Forming

Lathe machine operations which are performed by holding the work by a chuck or a faceplate or an angle plate are:

- Drilling
- Reaming
- Boring
- Contour boring
- Taper boring
- Tapping
- Under cutting
- Internal thread cutting
- Parting-off

1.1.3 The operation which is performed by using special attachments is:

- Grinding
- Milling

Turning:

It is the most common type of operation in all lathe operations. Turning is the operation of removing the excess material from the workpiece to produce a cylindrical surface to desired length.

The job held between the Centre and a chuck and rotating at a required speed. The tool moves in a longitudinal direction to give the fees towards the headstock with proper depth of cut. The surface finish is very good.

Facing:

It is an operation of reducing of reduction the length of the workpiece by feeding the perpendicular to the lathe axis. This operation of reducing a flat surface on the end of the workpiece. For this operation, regular turning tool or facing tool may use. The cutting edge of the tool should set to the same height as the Centre of the workpiece.

Facing consists of 2 operations

Roughing: Here the depth of cut is 1.3mm
Finishing: Here the depth of cut is 0.2-0.1mm.

Chamfering Operation:

It is the operation of getting a beveled surface at the edge of a cylindrical workpiece. This operation is done in case of bolt ends shaft ends. Chamfering helps to avoid damage to the sharp edges and protect the operation by hands. Chamfering on bolt helps to screw the nut easily.

Knurling Operation:

It is an operation of obtaining a diamond shape on the workpiece for the gripping purpose. This is done to provide better gripping surfaces when operated by hands. It is done using a knurling tool. The tool consists of a set of hardened steel roller, roller and it is held rigidly on the tool post.

Knurling is done at the lowest speed available on a lathe. It is done on the handles and also in case of ends of gauges. The feed varies from 1 to 2mm per revolution. Two or three cuts may be necessary to give the full impression.

Thread Cutting:

It is the important operation in the lathe to obtain the continuous “helical grooves” or “threads”.

When the threads or helical grooves are formed on the surface of the workpiece is called external thread cutting. When the threads or helical grooves are formed on the inner surface of the workpiece is called internal thread cutting. The workpiece is rotating between the two centers i.e., live Centre and dead Centre so the lathe.

Here the tool is moved longitudinally to obtain the required type of thread. When the tool is moved from the right to left, we get the left-hand thread. Similarly, when the tool is moved from left to right, we get the right-hand thread.

Here the motion of the carriage is provided by the lead screw. A pair of change gears drives the lead screw and by rotating the handle the depth if cut can be controlled.

Grooving:

It is the process of reducing the diameter of a workpiece over a very narrow surface. It is done by a groove tool. A grooving tool is similar to the parting-off tool. It is the often done at the end of a thread or adjacent to a shoulder to leave a small margin.

Forming:

It is the process of turning a convex, concave or any irregular shape. Forming-turning may be accomplished by the following method:

- Using a forming tool.
- Combining cross and longitudinal feed.
- Tracing or copying a template.

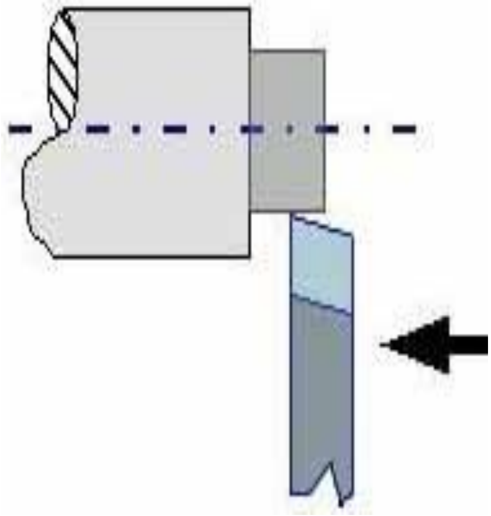

Figure 1.2a. Producing a Cylindrical Surface

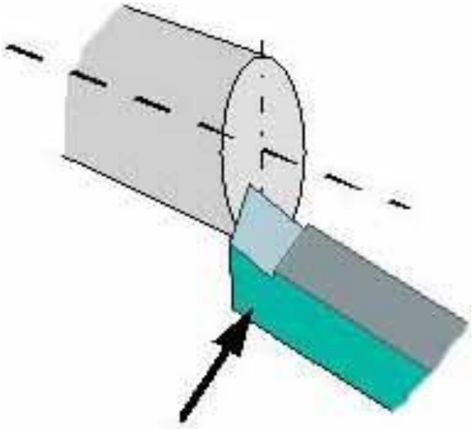

Figure 2b. Producing a Flat Surface

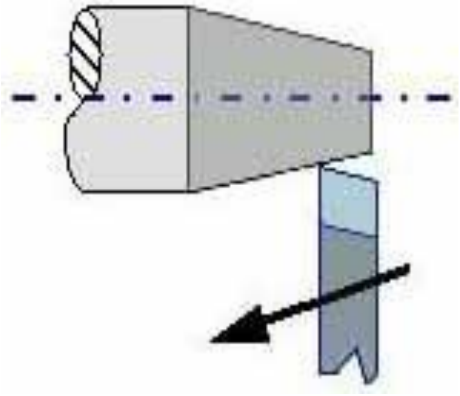

Figure 2c. Taper Turning

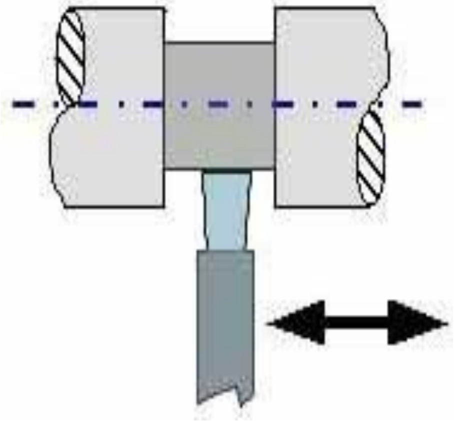

Figure 2d. Parting Off / Under Cutting

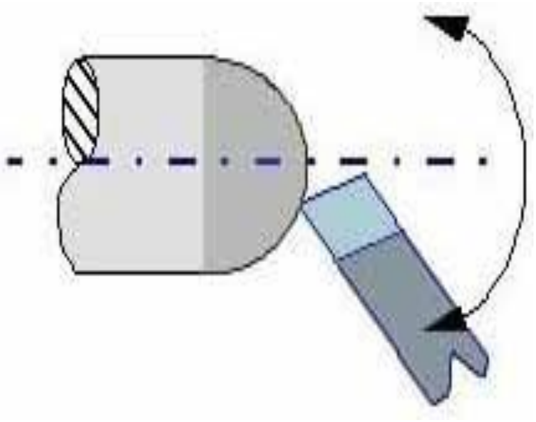

Figure 2e. Radius Turning Attachment

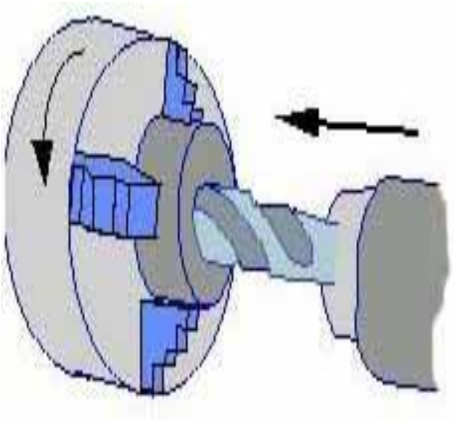

Figure 2f. Drilling on a Lathe

Cutting Tools

The tool used in a lathe is known as a single point cutting tool. It has one cutting edge or point whereas a drill has two cutting edges and a file has numerous points or teeth.

The lathe tool shears the metal rather than cuts as will be seen later and it can only do so if there is relative motion between the tool and the workpiece. For example, the work is rotating and the tool is moved into its forms an obstruction and shearing takes place. Of course, the amount of the movement is of paramount importance – too much at once could for instance result in breakage of the tool.

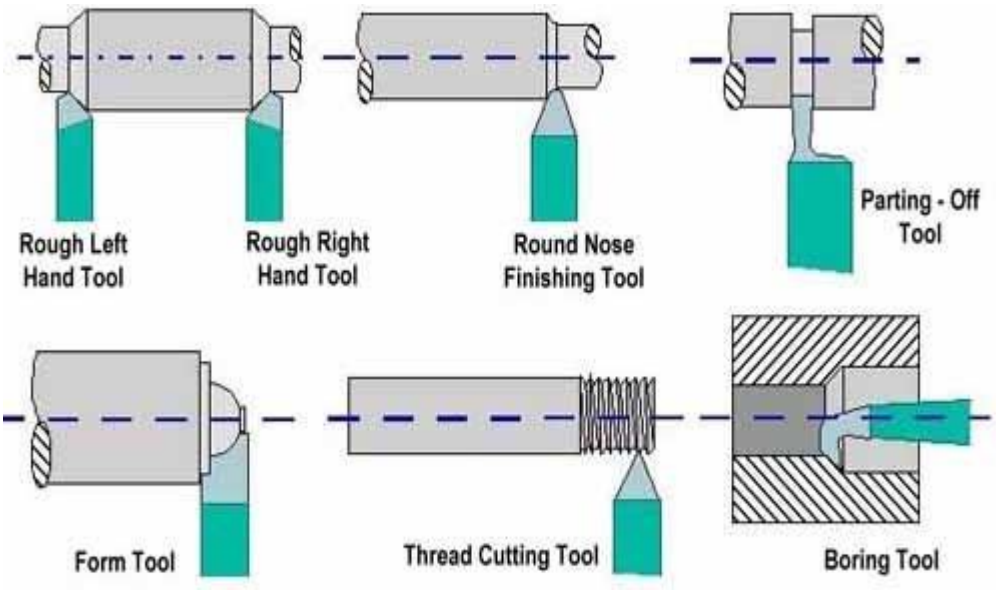

Figure 1.3. Types of Cutting Tool

The type and design of the tools selected will depend on the job in hand, the machining operation selected and material to be cut. The correct tool especially.

The various face angles are essential if the operation is to be dine in a cost effective (i.e., productive) way. The tools used in the lathe are various, some of which are shown in figure 3.

1.2.1 Tool Angle

There are three important angles in the construction of a cutting tool rake angle, clearance angle and plan approach angle.

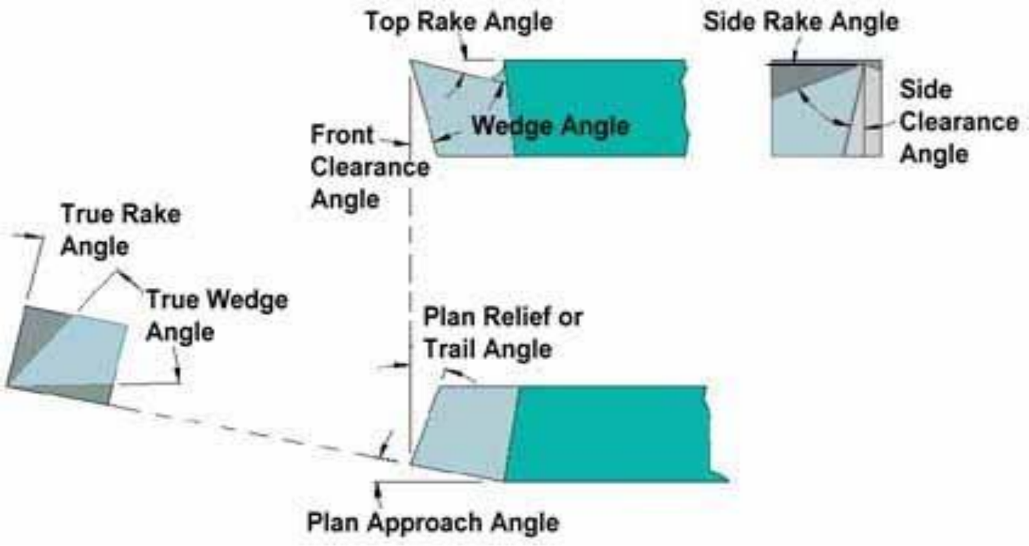

Figure 1.4. Main Features of a Single Point Cutting Tool

Rake Angle

Rake angle is the angle between the top face of the tool and the normal to the work surface at the cutting edge. In general, the larger the rake angle, the smaller the cutting force on the tool, since for a given depth of cut the shear plane AB, shown in Figure 4 decreases as rake angle increases. A large rake angle will improve cutting action, but would lead to early tool failure, since the tool wedge angle is relatively weak. A compromise must therefore be made between adequate strength and good cutting action.

Metal Being Cut	Cast Iron	Hard Steel/ Brass	Medium Carbon Steel	Mild Steel	Aluminum
Total Rake Angle	0°	8°	14°	20°	40°

Table 1.1 Typical value for top rake angle

Clearance Angle

Clearance angle is the angle between the flank or front face of the tool and a tangent to the work surface originating at the cutting edge. All cutting tools must have clearance to allow cutting to take place. Clearance should be kept to a minimum, as excessive clearance angle will not improve cutting efficiency and will merely weaken the tool. Typical value for front clearance angle is 6° in external turning.

Plan Profile of Tool

The plan shape of the tool is often dictated by the shape of the work, but it also has an effect on the tool life and the cutting process. Figure 6 shows two tools, one where a square edge is desired and the other where the steps in the work end with a chamfer or angle. The diagram shows that, for the same depth of cut, the angled tool has a much greater length of cutting edge in contact with the work and thus the load per unit length of the edge is reduced. The angle at which the edge approaches the work should in theory be as large as possible, but if too large, chatter may occur. This angle, known as the Plan Approach Angle, should therefore be as large as possible without causing chatter.

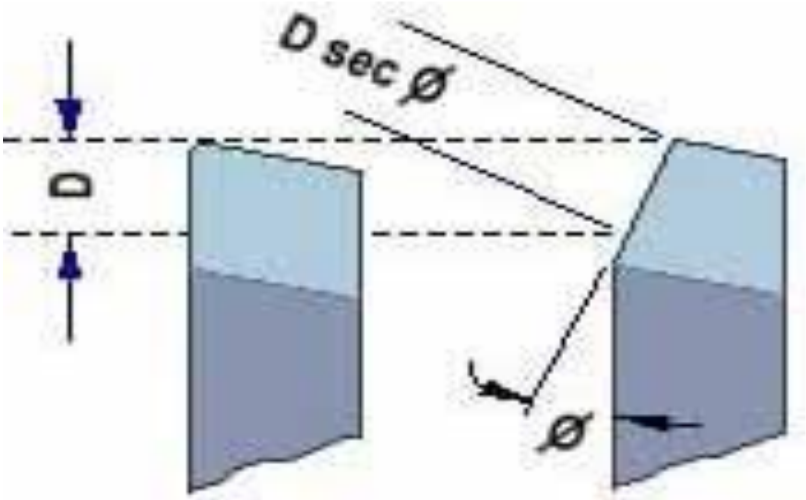

Figure 1.5. Plan Approach Angle.

The trailing edge of the tool is ground backwards to give clearance and prevent rubbing and a good general guide is to grind the trailing edge at 90° to the cutting edge. Thus, the Trail Angle or Relief Angle will depend upon the approach angle.

A small nose radius on the tool improves the cutting and reduces tool wear. If a sharp point is used it gives poor finish and wears rapidly.

1.3. Basic Metal Cutting Theory

The usual conception of cutting suggests clearing the substance apart with a thin knife or wedge. When metal is cut the action is rather different and although the tool will always be wedge shaped in the cutting area and the cutting edge should always be sharp the wedge angle will be far too great for it to be considered knife shaped. Consequently, a shearing action takes place when the work moves against the tool.

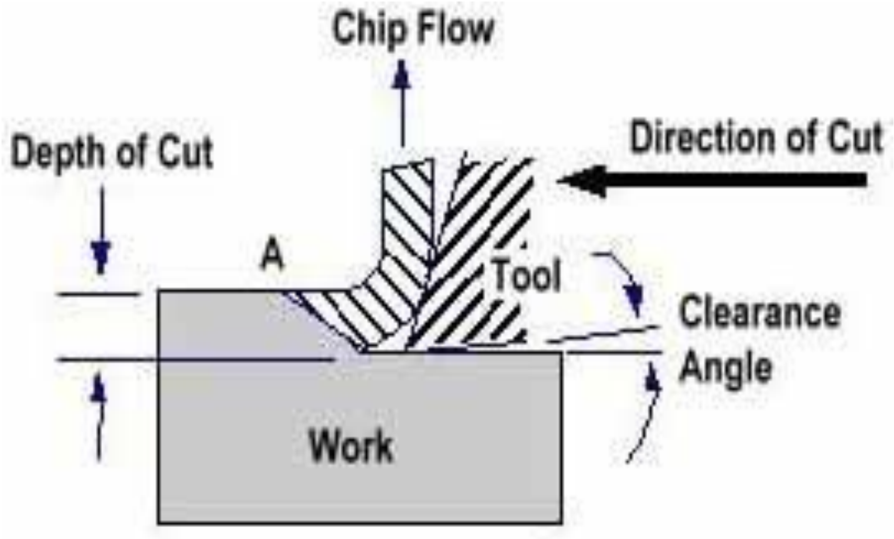

Figure 1.6. Basic Metal Cutting Theory

Figure 1.6 shows a tool being moved against a fixed work piece. When the cut is in progress the chip presses heavily on the top face of the tool and continuous shearing takes place across the shear plane AB. Although the Figure shows a tool working in the horizontal plane with the workpiece stationary, the same action takes place with the work piece revolving and the tool stationary.

1.3.1 Chip Formation &Chip Breaker

The type of chip produced depends on the material being machined and the cutting conditions at the time. These conditions include the type of tool used tool, rate of cutting condition of the machine and the use or absence of a cutting fluid.

Continuous Chip

This leaves the tool as a long ribbon and is common when cutting most ductile materials such as mild steel, copper and Aluminums. It is associated with good tool angles, correct speeds and feeds, and the use of cutting fluid.

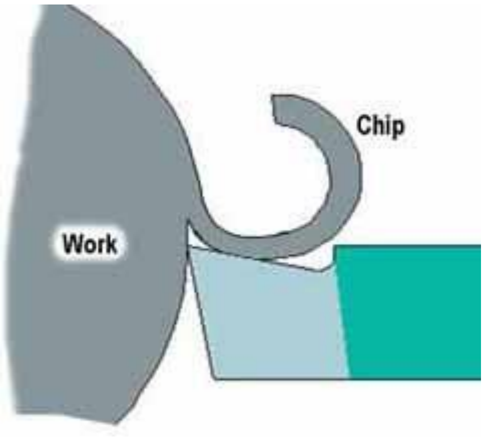

Figure 1.7. Continuous Chip

Discontinuous Chip

The chip leaves the tool as small segments of metal resulted from cutting brittle metals such as cast iron and cast brass with tools having small rake angles. There is nothing wrong with this type of chip in these circumstances.

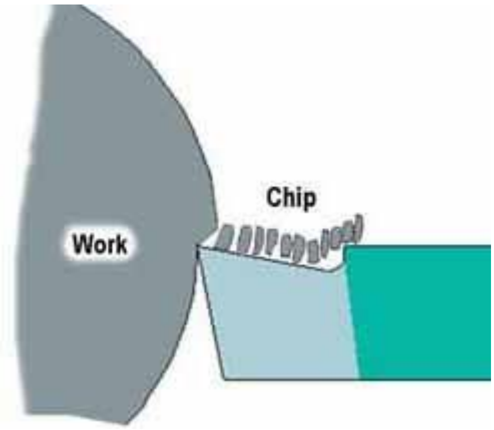

Figure 1.8. Discontinuous Chip

Continuous Chip with Built-up Edge

This is a chip to be avoided and is caused by small particles from the workpiece becoming welded to the tool face under high pressure and heat. The phenomenon results in a poor finish and damage to the tool. It can be minimized or prevented by using light cuts at higher speeds with an appropriate cutting lubricant.

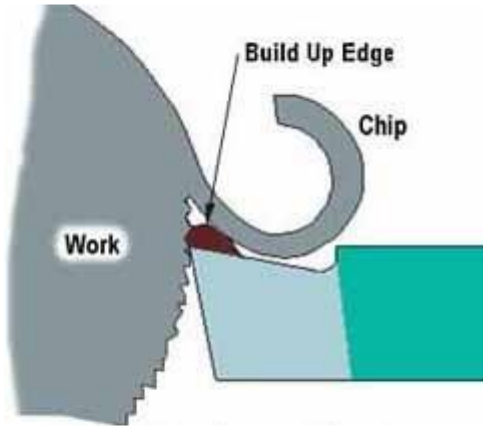

Figure 1.9. Continuous Chip with Buildup Edge

Chip Breaker

A chip breaker is used to break the continuous chip into sections so that the chips cannot tangle around the cutting tool. The simplest form of chip breaker is made by grinding a groove on the tool face a few millimeters behind the cutting edge.

1.4. Cutting Parameters

As you proceed to the process of metal cutting, the relative `speed' of work piece rotation and `feed' rates of the cutting tool coupled to the material to be cut must be given your serious attention. This relationship is of paramount importance if items are to be manufactured in a cost-effective way in the minimum time, in accordance with the laid down specifications for quality of surface finish and accuracy. You, as a potential supervisory / management level engineer, must take particular note of these important parameters and ensure that you gain a fundamental understanding of factors involved.

1.4.1. Cutting Speed

All materials have an optimum Cutting Speed and it is defined as the speed at which a point on the surface of the work passes the cutting edge or point of the tool and is normally given in meters/min. To calculate the spindle Speed required,

$$N = \frac{Cs\ X\ 1000}{\pi d}$$

Where:

N = Spindle Speed (RPM)
CS = Cutting Speed of Metal (m/min) d = Diameter of Work piece.

Table 2 shows the cutting speed recommended for some common metals. It may be possible to exceed these speeds for light finishing cuts. For heavy cuts they should be reduced.

Metal	**Meters /Min**
Cast Iron	20-28
Mild Steel	18-25
High Speed Steel	12-18
Brass	45-90
Bronze	15-21
Aluminum	up to 300

Table 2. Cutting Speed

1.4.2. Feed

The term `feed' is used to describe the distance the tool moves per revolution of the workpiece and depends largely on the surface finish required. For roughing out a soft material a feed of up to 0.25 mm per revolution may be used. With tougher materials this should be reduced to a maximum of 0.10 mm/rev. Finishing requires a finer feed then what is recommended.

1.4.3 Depth of Cut

The depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of the work piece.

1.5. Cutting Fluid & Lubricant

The aims in metal cutting are to retain accuracy, to get a good surface finish on the workpiece and at the same time to have a longer tool life.

However, during the metal cutting process heat is generated due to:

- The deformation of the material ahead of the tool
- Friction at the tool point

Heat generated due to friction can readily be reduced by using a lubricant. Heat caused by deformation cannot be reduced and yet it can be carried away by a fluid. Thus, the use of a cutting fluid will serve to reduce the tool wear, give better surface finish and a tighter dimensional control.

The proper selection, mixing and application of cutting fluids is however often misunderstood and frequently neglected in machining practice. In order that the cutting fluid performs its functions properly it is necessary to ensure that the cutting fluid be applied directly to the cutting zone so that it can form a film at the sliding surfaces of the tool.

Cutting fluids in Common Use

Water:

It has a high specific heat but is poor in lubrication and also encourages rusting. It is used as a cooling agent during tool grinding.

Soluble oils:

Oil will not dissolve in water but can be made to form an intimate mixture or emulsion by adding emulsifying agents. The oil is then suspended in the water in the form of tiny droplets. These fluids have average lubricating abilities and good cooling properties. Soluble oils are suitable for light cutting operations on general purpose machines where high rates of metal removal are often not of prime importance. There are many forms of soluble oil in the market and the supplier’s instruction should be followed regarding the proportions of the `mix'.

Mineral Oils:

They are used for heavier cutting operations because of their good lubricating properties and are commonly found in production machines where high rates of metal removal are employed. Mineral oils are very suitable for steels but should not be used on copper or its alloys since it has a corrosive effect.

Vegetable Oils:

They are good lubricants but are of little used since they are liable to decompose and smell badly.

1.6. CNC Lathe

Numerical-control lathes differ from hydraulically controlled tracer lathes primarily in that their cutting tools are controlled electronically. All tool movements during cuts, as well as all tool indexing, cross-slide operations, and changes of speed and feed, are pre-engineered and programmed on a punched tape for electronic control of all machine movements. Advantages of the NC lathe include low inventory of tooling and fully controlled cutting conditions. For copying work, NC lathes have the capability of machining any cylindrical form without the need for a template. However, compared to tracer lathes, NC machines can be quite expensive.

An important advance in the philosophy of machine tool numerical control that took place in the early 1970s was the shift toward the use of computers instead of controller units in NC systems. This produced both computer numerical control (CNC) and direct numerical control (DNC). Computer numerical control is a self-contained NC system for a single machine tool including a dedicated computer controlled by stored instructions to perform some or all of the basic NC functions. With DNC, several machine tools are directly controlled by a central computer. Of the two types of computer control, CNC has become much more widely used for manufacturing systems, machine tools, welders, and laser beam cutters mainly because of its flexibility and the lower investment required. The preference of CNC over DNC is increasing as a result of the availability and declining costs of minicomputers and microcomputers.

One of the objectives of CNC systems is to replace as much of the conventional NC hardware as possible with software and to simplify the remaining hardware. There are many ways in which functions can be shared between software and hardware in such systems, but all involve some hardware in the controller dedicated to the individual machine. This hardware must contain at least the servo amplifiers, the transducer circuits, and the interface components, as shown in Fig. 1.10

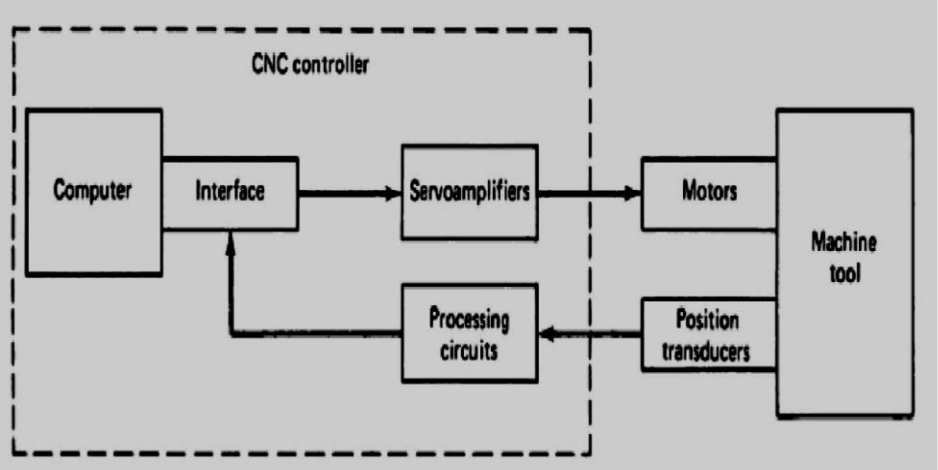

Fig. 1.10. Block diagram of a CNC machine

The software of a CNC system consists of at least three major programs: A part program, A service program, A control program the part program contains a description of the geometry of the part being produced and the cutting conditions, such as spindle speed and feed rate. The service program is used to check, edit, and correct the part program and to run system diagnostics. The control program accepts the part program as input data and produces signals to drive the axes of motion of the machine.

The CNC controllers of the 1980s are more powerful and more user friendly than earlier units. They incorporate troubleshooting features such as on-board diagnostics, which allow self-testing of the controller, and simulation mode, which is used to test part programs without generating axes motions. Many controllers offer high-level programming facilities, three-dimensional tool path animation with graphics, tool data base, and pre-selection of cutting parameters. The modern machine controller is a workstation. It is capable of communicating with other controllers and of being integrated into a flexible manufacturing system in the future, thus permitting the gradual construction of a full flexible manufacturing system. Numerical control was introduced and developed in the metalworking industry, and the largest concentration of NC equipment remains in metalworking shops. Numerical control has been successfully implemented for turning, milling, drilling, grinding, boring, punching, and electrical discharge machines. It is interesting to note that numerical control has made possible the development of machines with basic capabilities that far surpass those of conventional machines. For example, sophisticated NC milling machines maintain control over five axes of motion and can literally sculpt complex surfaces. A new breed of NC machine tool is the machining center and the turning center, which incorporate the functions of many machines into a single device. A machining center can access multiple tools to perform such operations as milling, drilling, boring, and tapping. A turning center is a powerful lathe equipped with an automatic tool changer. Other types of NC machines include welding machines, drafting machines, tube benders, inspection machines, and wiring machines in the electronics industry.

A common feature in numerical control and robotics is that the required path of the tool is generated by the combined motion of the individual axes. In numerical control, the tool is the cutting tool, such as a milling cutter or a drill; in robotics, the tool is the instrument at the far end of the manipulator, which might be a gripper, a welding gun, or a paint spraying gun. Robot systems, however, are more complex than machine tool CNC systems for the reason discussed below.

Machine tools require control of the position of the tool cutting edge in space. In many cases, the control of three axes is adequate. Robots require the control of both the position of the tool center point and the orientation of the tool; this is achieved by controlling six axes of motion (or degrees of freedom). Some robot systems use more than six axes, and some CNC machines use more than three axes of motion. A typical example is the addition of a rotary table to a three-axis milling machine. On the other hand, many robot systems use fewer than six axes, and in such cases the wrist section contains fewer than three degrees of freedom. Similarly, there are CNC machines with only two numerically controlled axes of motion.

1.6.1. Fundamentals of Numerical Control

Numerical control equipment has been defined by the Electronic Industries Association (EIA) as a system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of these data. In a typical NC or CNC system, the numerical data required for producing a part are maintained on a disk or on a tape and called the part program. The part program is arranged in the form of blocks of information. Each block contains the numerical data required to produce one segment of the work-piece profile. The block contains, in coded form, all the information needed for processing a segment of the work- piece: the segment length, its cutting speed, feed rate, and so on. Dimensional information such as length, width, and radii of circles and the contour form such as linear, circular, or other are taken from an engineering drawing. Dimensions are given separately for each axis of motion i.e., X, Y, and so on. Cutting speed, feed rate, and auxiliary functions such as coolant on and off, spindle direction, clamp, and gear changes are programmed according to surface finish, tolerance, and machining requirements.

Compared to a conventional machine tool, the NC system replaces the manual actions of the operator. In conventional machining, a part is produced by moving a cutting tool along a work- piece by means of powered slides that are engaged and disengaged by an operator. Contour cuttings are performed by an expert operator by sight. On the other hand, the operators of NC machine tools need not be skilled machinists. They only have to monitor the operations of the machine, operate the tape reader, and load and remove the work-piece. Most intellectual operations that were formerly done by the operator are now included in the part program. However, because the operator works with a sophisticated and expensive system, intelligence, clear thinking, and good judgment are essential qualifications of a good NC operator.

Preparing the part program of an NC machine tool requires a part programmer. The part programmer should possess knowledge and experience in mechanical engineering fields. Knowledge of tools, cutting fluids, fixture design techniques, machinability data, and process engineering are all of considerable importance. The part programmer must be familiar with the function of NC machine tools and machining processes and must decide on the optimum sequence of operations. The part program can be written manually, or a computer-assisted language, such as the automatically programmed tool language, can be used. In NC machines, the part dimensions are presented in part programs by integers. In CNC machines, the dimensions in part programs are sometimes expressed as numbers with a decimal point, but are always stored in the computer as integers. Each unit of these integers corresponds to the position resolution of the axes of motion and is referred to as the basic length unit (BLU). The BLU is also known as the increment size or bit weight, and in practice it corresponds approximately to the accuracy of the NC system.

In NC and CNC machine tools, each axis of motion is equipped with a separate driving device, which replaces the hand wheel of the conventional machine. The driving device may be a dc motor, a hydraulic actuator, or a stepping motor. The type selected is determined by the power requirements and the machine.

An axis of motion in numerical control means an axis in which the cutting tool moves relative to the work-piece. This movement is achieved by the motion of the machine tool slides. The main three axes of motion are referred to as the X-, Y-, and Z-axes. The Z axis is perpendicular to both X and Y in order to create a right-hand coordinate system. For example, in a vertical drilling machine (as one faces the machine), a +X command moves the worktable from left to right, a +Y command moves it from front to back, and a +Z command moves the drill up, away from the work-piece. The X-, Y-, and Z-axes are always assigned to create a right-hand Cartesian coordinate system.

Each axis of motion also has a separate control loop. The control loops of NC or CNC systems use two types of feedback devices shown in fig. 3, tachometers to monitor velocity and encoders or other position transducers (for example, resolvers) to measure position. The controller compares the actual position with the required one and generates an error. The control loop is designed in such a way as to reduce the error, that is, the loop is a negative-feedback type. A common requirement of continuous-path NC and CNC systems is the generation of coordinated movement of the separately driven axes in order to achieve the desired path of the tool. This coordination is accomplished by interpolators. Numerical control systems contain hardware interpolators, but in CNC systems interpolators are implemented by software.

1.6.2. Advantages of NC Systems

It has been clearly shown that NC manufacturing reduces the number of direct employees because fewer multipurpose NC machines are required and, in some cases, one operator can operate more than one machine. However, the ratio of indirect to direct employees might increase, and in turn, overall employment in the industry might rise despite increased automation and mechanization. Output would of course also increase. Realistically, then, the advantage is not in lowering labor costs but in increasing the output per man-hour. Handling costs with NC technology have decreased, in some cases remarkably. Setup times have been substantially reduced, and actual productive time has been substantially increased. A further savings of time is achieved while passing from one operation to another during the machining of the work-piece. With a conventional machine tool, the work must be stopped at such points because the operator must go to the next step. The operator must stop the cutting process frequently and measure the part dimensions to ensure that the material is not overcut. It has been proved that the time wasted on measurements is frequently 70 to 80% of the total working time. The rate of production is also decreased because of operator fatigue. In NC systems, these problems do not exist. Because the accuracy is repeatable with numerical control, inspection time is also reduced.

Numerical control produces higher-quality parts and makes possible the accurate manufacture of more complex designs without the usual loss in accuracy encountered in conventional manufacturing. Producing a part that must be cut with an accuracy of 0.01 mm or better may take a considerable amount of time using conventional methods. In numerical control using single-axis motion, obtaining such accuracies is the state-of-the-art, and they are maintained throughout the entire range of cutting speeds and feed rates. Another intangible advantage of numerical control is the production of complex parts that are not feasible in conventional manufacturing. Complex- contour cutting in three dimensions cannot be performed by manual operation. Even when it is possible, the operator must manipulate the two hand wheels of the table simultaneously while maintaining the required accuracy; thus, it becomes possible only when the part is simple and requires relatively low accuracies. It is obvious that in such work the NC machines save a considerable amount of time. Compared to conventional machining methods, the

NC machine tool has the following advantages:

- complete flexibility; a part program is needed only for producing a new part
- Accuracy is maintained through the full range of speeds and feeds
- The possibility of manufacturing a part of complicated contour
- A shorter production times
- 5. Higher productivity achieved by saving indirect time, such as setting up and adjusting the machine and using one operator to monitor several machining operations, or by using completely automatic operation in unmanned production.

1.6.3. NC Programming

Most NC and CNC machine tools use off-line programming methods, which can be either manual or computer assisted, such as programming with the aid of the automatically programmed tool language. During off-line programming, the machine remains in operation while a new part program is being written. Typically, when a part program is ready, it is stored on a punched tape or a floppy disk. The tape or disk is taken to the machine shop and loaded into the machine tool controller, and the part is subsequently produced. Manual part programs are written by programmers. First, the programmers must determine the machining parameters and the optimum sequence of operations to be performed. Based on this sequence, they calculate the tool path and write a manuscript. Each line of the manuscript, which is referred to as a block, contains the required data for transferring the cutting tool from one point to the next, including all machining instructions that should be executed either at the point or along the path between the points. A typical line Program according to this standard is as follows:

N10

G01

X-52000

Y9100

F315

S717

T65432

MO3 (EB)

The letter and the number that follows it are referred to as a word. For example, X- and M03 are words. The first letter of the word is the word address. Word addresses are denoted as follows: N, sequential number, G, preparatory function; X and Y, dimensional words; F. feed rate code; S, speed code; T, tool code; M, miscellaneous function; and EB, end-of-block character. The EB character is not printed but only punched or coded, and it is usually the carriage return code, thus permitting a new line to begin immediately afterward. The EB character indicates to the NC controller that the current reading is completed and that the axes of motion must start up. When this motion is accomplished, the next block is read.

1.7. Cutting Tools

Cutting tool is any tool that is used to remove material from the work-piece by means of shear deformation. Cutting may be accomplished by single-point or multipoint tools. Single-point tools are used in turning, shaping, planning and similar operations, and remove material by means of one cutting edge. Milling and drilling tools are often multipoint tools. Grinding tools are also multipoint tools. Each grain of abrasive functions as a microscopic single-point cutting edge, and shears a tiny chip. Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process. Also, the tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the work-piece without the rest of the tool dragging on the work-piece surface. The angle of the cutting face is also important, as is the flute width, number of flutes or teeth, and margin size. In order to have a long working life, all of the above must be optimized, plus the speeds and feeds at which the tool is run.

Principal categories of cutting tools include single point lathe tools, multipoint milling tools, drills, reamers, and taps. All of these tools may be standard catalog items or tooling designed and custom- built for a specific manufacturing need.

The number one error when selecting tooling is calculating monetary savings based on lowest cost per tool, rather than on maximized productivity and extended tool life. To effectively select tools for machining, a machinist or engineer must have specific information about the following:

- The starting and finished part shape
- The work-piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool

Changes in any of these conditions may require a thorough review of any cutting tool selection.

Different machining applications require different cutting tool materials. The ideal cutting tool material should have all of the following characteristics:

- Harder than the work it is cutting
- High temperature stability
- Resists wear and thermal shock
- Impact resistant
- Chemically inert to the work material and cutting fluid

No single cutting tool material incorporates all these qualities. Instead, trade-offs occur among the various tool materials. For example, ceramic cutting tool material has high heat resistance, but has a low resistance to shock and impact. Every new and evolving tool development has an application where it will provide superior performance over others. Many newer cutting tool materials tend to reduce, but not eliminate the applications of older cutting tool materials.

1.7.1. Single Point HSS Tool

Single point cutting tools ground to specific shapes are frequently used to produce contours on work-pieces when tool travel is limited to straight-line movement, most metal removal in lathe turning is accomplished with single-point tools. Single-point tools may be produced from a solid bar of tool steel by grinding the appropriate cutting edge on one end, or they may be made of less- costly stock and provided with a tip, or insert, of carbide or other cutting material. The insert may be held in place mechanically or by brazing, soldering, or welding. Brazed, soldered, or welded inserts are resharpened after becoming dull through use; inserts held in place mechanically are usually of the disposable type.

Design of Single-Point Tools

Standard angles for single-point tools are illustrated and named in Fig. 4 which shows how back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle, side cutting- edge angle, and nose radius are related in order to aid engineers in designing single-point cutting tools.

Back rake angle

It is the angle between the cutting face of the tool and the shank or holder, measured parallel to the side of the shank or holder. The angle is positive if, as shown in Fig. 4, it slopes from the cutting point downward toward the shank, and negative if it slopes upward toward the shank.

Side rake angle

It is the angle between the cutting face of the tool and the shank or holder, measured perpendicular to the side of the shank or holder. The angle is positive if, as shown in Fig. 4, it slopes downward away from the cutting edge to the opposite side of the shank, and negative if it slopes upward.

End relief angle

It is the angle between the end face of the tool and a line drawn from the cutting-edge perpendicular to the base of the shank or holder and usually is measured at right angles to the end cutting edge.

Side relief angle

It is the angle between the side flank immediately below the side cutting edge and a line drawn through the side cutting edge perpendicular to the base of the tool or tool holder and usually is measured at right angles to the side flank.

End cutting-edge angle

It is the angle between the end cutting edge of the tool and a line perpendicular to the side of the shank. Side cutting-edge angle, also called lead angle, is the angle between the side cutting edge and the projected side of the shank or holder.

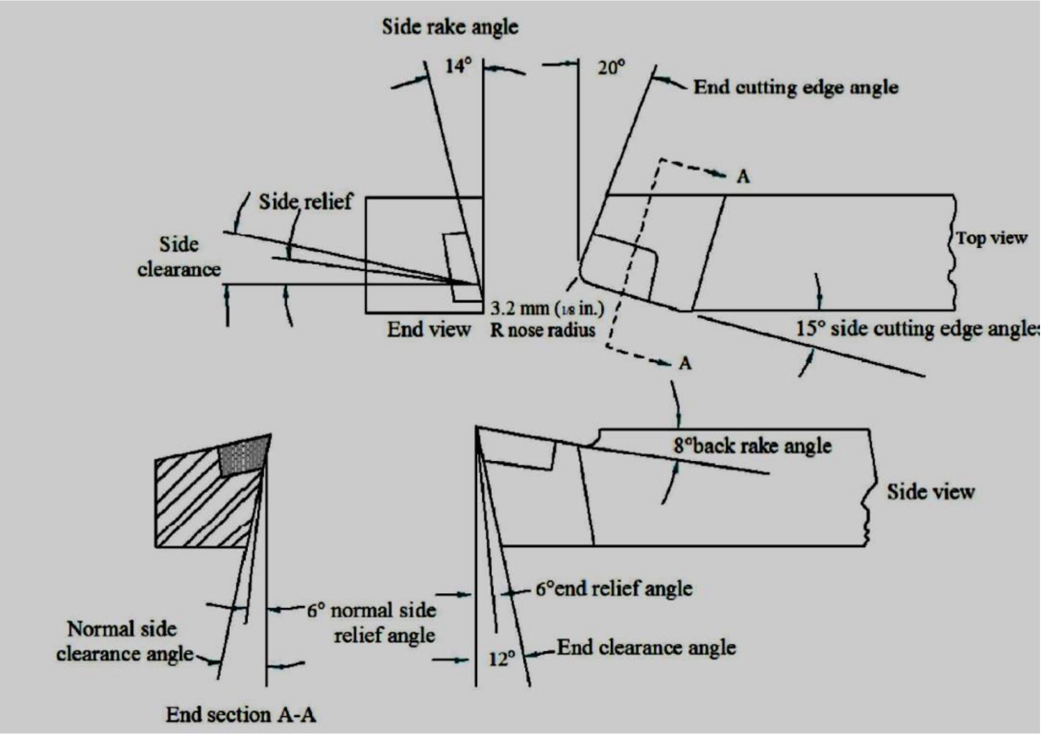

Fig. Geometry of single point cutting tool

Nose radius

It is the radius on the tool between the end and the side cutting edges. The nose contour, normally specified as a radius, removes the fragile corner of the tool, prolongs tool life, and improves finish. The radius may be large for maximum strength or for rough cutting tools, but it may be reduced for light feeds. A radius too large may cause chatter, but the larger it is without chattering, the better the finish.

Tool design influences the power required at the tool point for turning. The side rake angle has the greatest effect. Tool design is particularly important in tracer lathe turning, for which only one tool is used to make all cuts. Because the minimum number of passes is desirable, so is the fastest rate of metal removal that is compatible with maintenance of dimensional and finish requirements. The use of only one cutting tool imposes severe restrictions on the shape of the tool. A tool often must be provided with a -3° side cutting edge angle and a 30° minimum end cutting-edge angle, resulting in a weak structure at the nose of the cutting edge. For this reason, heavy feed forces often must be avoided, if they have not already been ruled out because of required finish. Thus, surface speed becomes the criterion for determining maximum rate of metal removal, and the design of the cutting tool becomes vitally important in obtaining maximum metal removal and tool life. Increasing the surface cutting speed increases tool temperatures and results in premature tool wear.

1.8. Cutting Tool Materials

As rates of metal removal have increased, so has the need for heat resistant cutting tools. The result has been a progression from high-speed steels to carbide, and on to ceramics and other super hard materials. Developed around the year 1900, high-speed steels cut four times faster than the carbon steels they replaced. There are over 30 grades of high-speed steel, in three main categories: tungsten, molybdenum, and molybdenum-cobalt based grades. Since the 1960s the development of powdered metal high-speed steel has allowed the production of near-net shaped cutting tools, such as drills, milling cutters and form tools. The use of coatings, particularly titanium nitride, allows high-speed steel tools to cut faster and last longer. Titanium nitride provides a high surface hardness, resists corrosion, and it minimizes friction.

In industry today, carbide tools have replaced high-speed steels in most applications. These carbide and coated carbide tools cut about 3 to 5 times faster than high-speed steels. Cemented carbide is a powder metal product consisting of fine carbide particles cemented together with a binder of cobalt. The major categories of hard carbide include tungsten carbide, titanium carbide, tantalum carbide, and niobium carbide. Each type of carbide affects the cutting tool’s characteristics differently. For example, a higher tungsten content increases wear resistance, but reduces tool strength. A higher percentage of cobalt binder increases strength, but lowers the wear resistance. Carbide is used in solid round tools or in the form of replaceable inserts. Every manufacturer of carbide tool offers a variety for specific applications. The proper choice can double tool life or double the cutting speed of the same tool. Shock resistant types are used for interrupted cutting. Harder, chemically-stable types are required for high-speed finishing of steel. More heat-resistant tools are needed for machining the super-alloys, like Inconel and Hastelloy.

There are no effective standards for choosing carbide grade specifications so it is necessary to rely on the carbide suppliers to recommend grades for given applications. Manufacturers do use an ANSI code to identify their proprietary carbide product line. Two thirds of all carbide tools are coated. Coated tools should be considered for most applications because of their longer life and faster machining. Coating broadens the applications of a specific carbide tool. These coatings are applied in multiple layers of under .001 of an inch thickness. The main carbide insert and cutting tool coating materials are titanium carbide, titanium nitride, aluminum oxide, and titanium carbonitride. Ceramic cutting tools are harder and more heat-resistant than carbides, but more brittle. They are well suited for machining cast iron, hard steels, and the super alloys.

Two types of ceramic cutting tools available are the alumina-based and the silicon nitride-based ceramics. The alumina-based ceramics are used for high speed semi- and final-finishing of ferrous and some non-ferrous materials. The silicon nitride-based ceramics are generally used for rougher and heavier machining of cast iron and the super alloys. Ceramic tools are produced from the materials used to coat the carbide varieties such as titanium carbides and nitrides. They are especially useful in chemically reactive machining environments, for final finishing and some turning and milling operations.

Super-hard tool materials are divided into two categories: cubic boron nitride and polycrystalline diamond. Their cost can be 30 times that of a carbide insert, so their use is limited to well-chosen, cost effective applications. Cubic boron nitride is used for machining very hard ferrous materials such as steel dies, alloy steels and hard-facing materials.

Polycrystalline diamond is used for non-ferrous machining and for machining abrasive materials such as glass and some plastics. In some high-volume applications, polycrystalline diamond inserts have outlasted carbide inserts by up to 100 times. All cutting tools are “perishable,” meaning they have a finite working life. It is not a good practice to use worn, dull tools until they break. This is a safety hazard which creates scrap, impacts tool and part costs, and reduces productivity. Apart from breakage, cutting tools wear in many different ways, including:

- Edge wear and flank wear
- Cratering or top wear
- Chipping
- Built-up edge
- Deformation
- Thermal cracking

Edge and flank wear are both normal, slow types of tool wear. If the work material is highly abrasive, as with certain cast-irons, this type of wear will accelerate. Cratering occurs behind the cutting edge, and happens often in machining long chipping steels. If the crater grows large enough and contacts the cutting edge, the tool fails immediately. Cratering can be overcome by using titanium or tantalum carbide tools.

on a tool edge is an unpredictable form of tool failure. It is sometimes started when a high point on an edge breaks away. A stronger carbide grade, different edge preparation, or lead angle change may eliminate chipping. Built-up edge is a deposit of work-piece material adhering to the rake face of an insert.

These deposits can break off, pulling out pieces of carbide from the tool. Ductile materials, such as softer steels, aluminum, and copper cause this problem. The use of higher rake angles, faster cutting speeds, and high-pressure cutting fluid all help eliminate built-up edge. Deformation of a tool or insert is due to heat build-up. Although very detrimental to the machining process, deformation is difficult to detect without the use of a microscope. Using a heat-resistant tool or reducing the cutting speed often help to prevent deformation. Thermal cracking occurs when inserts go through rapid heating and cooling cycles. Causes include interrupted cutting and poor application of cutting fluids.

1.8.1. Characteristics of Tool Material

For efficient cutting a tool must have the following properties:

Hot Hardness

This means the ability to retain its hardness at high temperatures. All cutting operations generate heat, which will affect the tool¡¦s hardness and eventually its ability to cut.

Strength and Resistance to Shock

At the start of a cut the first bite of the tool into the work results in considerable shock loading on the tool. It must obviously be strong enough to withstand it.

Low Coefficient of Friction

The tool rubbing against the workpiece and the chip rubbing on the top face of the tool produce heat which must be kept to a minimum.

1.8.2. Tool Materials in Common Use

High Carbon Steel Contains 1 - 1.4% carbon with some addition of chromium and tungsten to improve wear resistance. The steel begins to lose its hardness at about 250° C, and is not favored for modern machining operations where high speeds and heavy cuts are usually employed.

High Speed Steel (H.S.S.)

Steel, which has a hot hardness value of about 600° C, possesses good strength and shock resistant properties. It is commonly used for single point lathe cutting tools and multi point cutting tools such as drills, reamers and milling cutters.

Cemented Carbides

An extremely hard material made from tungsten powder. Carbide tools are usually used in the form of brazed or clamped tips. High cutting speeds may be used and materials difficult to cut with HSS may be readily machined using carbide tipped tool.

Tool life

As a general rule the relationship between the tool life and cutting speed is $VT^n = C$

where;

V = cutting speed in m/min
T = tool life in min
C = a constant
For high-speed steel tools the value of C ranges from 0.14 to 0.1 and for carbide tools the value would be 0.2.

1.9. Effect of Cutting Parameters on Responses

Surface finish is one of the most important quality characteristics in manufacturing industries which influences the performance of mechanical parts as well as production cost. In recent times, modern industries are trying to achieve the high-quality products in a very short time with less operator input. For that purpose, the computer numerically controlled machine tools with automated and flexible manufacturing systems have been implemented. In order to improve the product quality and efficiency in machining, recently, there has been intensive computation focusing on surface roughness at international level. This computation can be observed in turning processes especially in aerospace and automotive industry by increasing the alternative solution for obtaining better surface roughness. A good quality turning surface can lead to improvement in strength properties such as fatigue strength, corrosion resistance and thermal resistance. In addition, the final surface roughness also affects several function attributes of parts like friction, wearing, light reflection, heat transmission, coating and ability of distributing and holding a lubricant. Right selection of tool geometry and cutting parameters that affect surface roughness are important factors especially in providing tolerance. The desired finish surface is usually specified and the appropriate processes are selected to reach the required quality.

Surface roughness is one of the prime factors in evaluating the quality of a component as it affects all the dimensions of quality mentioned above. Since it is a very important factor of quality it has received serious attention for many years. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes and aesthetic requirements. Surface roughness imposes one of the most critical constraints for selection of machines and cutting parameters in process planning.

Surface Roughness is generally the vertical elevations made on the surface of the metal, for example, grooves from the tool or from each grinding granule on a grinding wheel. Although roughness is usually 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 cost of a component and its performance in application.

Therefore, it is necessary to develop methods, which can be used for the prediction of the surface roughness according to technological parameters.

Measuring surface roughness is a crucial concern for an immense range of industries and applications, from auto component wear to medical implant efficacy, from micro electro-mechanical systems inspection to semiconductor thin-film uniformity. The performance and value of thousands of products and systems – from designer sunglass to advanced personal digital devices is governed by characterizing and controlling micro scale surface features, including micro-inch surface roughness. Many of the major advances in science and industry over the past half century would not have been possible without accurate surface roughness metrology.

The parameter most used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length.

1.9.2. Effect of Feed Rate and Depth of Cut on Surface Roughness

As expected, the roughness increases with feed rate. On the roughness profiles, the feed marks also become clearer and prominent. At lower feed rates the roughness becomes independent of feed rate and is a function of nose radius only. This causes higher micro roughness i.e. superimposed irregularities over the grooves generated by chip removal. The plastic flow component is comparatively more. Similarly, when feed rate is large and nose radius small, the surface roughness depends mainly on feed rate compared to nose radius. The plastic flow is opposite to feed direction with higher height at low feed rate which can also lead to higher roughness at low feed rate. Similar difference has been reported whereby lower roughness occurred at higher feed rates owing to pure cutting action and relative absence of swelling.

In the same way at low feed rate material gets ploughed rather than form chips. In this way there exists a possibility of the existence of optimum feed rate. Though the theory suggests roughness to be a function of square of feed rate, in practice it is more like directly related to feed rate. This can be due to flattening of ridges due to side flow or tool work relative vibrations. These effects are corroborated by the Fourier transforms. The generation of several harmonics at lower feed rates due to ploughing action are clearly seen which conforms to the arguments presented for the micro roughness at low feed rates. The reduction in micro roughness and pronounced periodicity is seen with the diminishing corroborates the previous argument that at high feed rate the dominant mechanism is of chip removal rather than plastic flow.

1.9.3. Effect of Cutting Speed and Nose radius on surface roughness

The surface finish decreases with cutting speed of up to 100 m/min. With increasing the cutting speed further, the surface roughness of the machined work pieces seams to increase for both the grades. This is due to the increased friction between work piece and tool interface, which eventually increases the temperature in the cutting zone. Hence the shear strength of the material reduces and the material behaves in a ductile fashion. Moreover, the duplex stainless steel is sticky in nature which makes the chips to detach from the work piece with utmost difficulty, thereby increasing the surface roughness.

The decrease in surface roughness with increasing cutting speed up to 100 m/min is due to the decreasing built up edge formation tendency with increasing cutting speed. However, further increase in cutting speed causes an increase in surface roughness. This can be attributed to the increasing cutting tool nose wear at higher cutting speeds of 120, 140 and 180 m/min. It can also be observed that the minimum Ra of machined surfaces is obtained when cutting speed is at 100 /min.

1.9.4. Effect of cutting parameters on material removal rate

The material removal rate , MRR, can be defined as the volume of material removed divided by the machining time. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the work- piece. Since the depth of cut is changing the material removal rate changes continuously during the process. In some cases, this may be important. For example, if cutting forces and the resulting work- piece and tool deflections are of interest. The changing amount of material being removed along the tapered shaft means the cutting force and so the deflections will change during the process.

The material removal rate is the volume of material removed per unit time. Volume of material removed per unit time. Volume of material removed is a function of speed, feed and depth of cut. Higher the values of these more will be the material removal rate. It can be calculated by using the following equations 3, 4, and

Let, Di = initial diameter of the workpiece, mm,
d = Depth of cut, mm and
f = Feed, mm/revolution.
Volume of material removed in one revolution = πD_i x d x f mm^3

MRR = πD_i x d x f x N mm^3/min.
In terms of cutting speeds V in m/min;
MRR = 1000 x v x d x f in mm^3/min

1.9.5. Effect of Cutting Parameters on Machining Time

The time during which a piece of equipment like machine, lathe, unit, or apparatus without direct participation of an operator, produces a change in the dimensions, shape, or state of a work-piece. The machining time depends on the characteristics of the manufacturing process; on the qualitative features of the raw material, semi-finished product, or stock; on the type of equipment and tool; and on the mechanization and automation of labor.

For machining time are calculated by determining the optimum operating schedule for the equipment, which ensures maximum output, minimum prime cost of the articles being processed, and the required quality level. For example, for metal cutting machine tools the standard machining time is determined according to well-grounded conditions of cutting (depth of cut, feed, cutting speed, and number of passes). Machining time may be reduced through the introduction of high-speed processing methods and by using high-performance equipment and instruments. As the level of mechanization and automation of production rises, the proportion of machining time in the standards of piece rate time for completing a unit or for completing one manufacturing operation increases. The machining time can be calculated by using the equations 6, and 7.

$L = l + l_1 + l_2$

l = Length of surface tube machined.

l1 = Distance required for feeding the tool cross wise to incraese the depth of cut in mm

l2 = over travel of the tool at the end of each cut in mm

L = Distance travelled by the tool in the direction of the feed in single cut

f = feed mm/rev, N = rpm

Machining time = $\frac{L}{fN}\ min$

1.9.6. Effect of Cutting Parameters on Machining Force

To machine metal at a specified speed, feed, and depth of cut, with a specified lubricant, cutting tool material, and geometry, generates cutting forces and consumes power. A change in any of the variables alters the forces, but the change is indirect in that the engineer does not specify the forces, only the parameters that generate those forces. Forces are important in that they influence the deflections in the tools, the work pieces, and the work holders, which in turn affect the final part size. Forces also play a role in chatter and vibration phenomena common in machining.

Obviously, the manufacturing engineer would like to be able to predict forces (and power) so that he can safely specify the equipment for a manufacturing operation, including the machine tool, cutting tool, and work holding devices. The relation to calculate force is given in equation 8.

F = k x d x f N
Were,
D = depth of cut in mm
F = feed per rotation in mm
K = specific cutting energy coefficient.

1.9.7. Effect of Cutting Parameters on Machining Power

Although one may wish to describe the energy per unit volume needed to form the chip, machine tools are typically rated in terms of power. Unit (or specific) power values can be calculated by dividing the power input to the process, F_cV, by the volumetric rate at which material is removed and then dividing this quantity by 33,000 to convert to horsepower. The specific power, P_s, is a measure of the difficulty involved in machining a particular material and can be used to estimate the total cutting power, P.

The specific power is the power required to remove a unit volume per unit time. Therefore, the specific and total powers are related as follows:

Where MRR is the material removal rate, or volume of material removed per unit time. The material removal rate can be computed as the uncut area multiplied by the rate at which the tool is moved perpendicular to the uncut area. Thus, the cutting parameters and machine tool kinematics define the material removal rate. There are many standard sources for specific power values for a variety of materials. Unfortunately, machine tools are not completely efficient. Losses due to component wear, friction, and other sources prevent some power from reaching the tool. Therefore, the gross

Power, P_g, needed by the motor can be defined as:

$$P_g = \frac{P}{\eta}$$

Where η is the efficiency of the machine

Power in Turning is the total power required in a turning operation can be calculated as

However, the material removal rate must be redefined for turning. Consider the turning operation, in which a billet of diameter *D* is turned with depth of cut *d* to diameter *D*1. The billet is rotated at *N* revolutions per minute, while the tool is fed at *f* r units (millimeters or inches) per revolution, which can be set directly on the machine. Recommended cutting speeds (in meters or feet per minute) are generally available from handbooks and can be converted to rotational speed where $V = DN$. Suggested feeds are also available.

Cutting power is an important parameter, especially in the case of rough operations, as it makes it possible to:

- Select and invest in a machine with a power output suited to the operation being carried out.
- Obtain the cutting conditions that allow the machines power to be used in the most effective way possible, so as to ensure optimal material removal rate while taking into account the capacity of the tool being used.

The required cutting power P, KW can be estimated using the following formula:

$$P = \frac{F\ X\ v}{60000}\ W$$

CHAPTER-2

LITERATURE SURVEY

Upinder Kumar Yadav et.al. [1] Conducted experiments to optimize surface roughness in CNC Turning by Taguchi method. Medium Carbon Steel (AISI 1045) of Ø: 28 mm, length: 17 mm are used for the turning experiments. An L27 orthogonal array, analysis of variance (ANOVA) and the signal-to-noise(S/N) ratio are used in this study. Three levels of machining parameters are used and experiments are done onSTALLION-100 HS CNC lathe. They concluded that feed rate is the most significant factor affecting surface roughness followed by depth of cut. Cutting speed is the least significant factor affecting surface roughness.

Suleiman Abdulkareem et.al. [2] investigated the influence of the three most important machining parameters of depth of cut, feed rate and spindle speed on surface roughness during turning of AISI 1045. Box Behnken experimental design method as well as analysis of variance (ANOVA) was used to analyze the influence of machining parameters on surface roughness height R_a. From the experiments they concluded that the feed rate is found to be the most important parameter effecting Ra, followed by cutting speed while spindle speed has the least effect. They also found that machining with high cutting speed and spindle speed has positive effect on Raas against feed rate.

M. Kaladharet. al. [3] done an experimental investigation for finding the effect of speed, feed, depth of cut, and nose radius on multiple performance characteristics, namely, surface roughness (R_a) and material removal rate (MRR)during turning of AISI 202 austenitic stainless steel using a CVD coated cemented carbide tool. Taguchi's L8 orthogonal array (OA) is selected for experimental planning. They found that the most significant parameter for surface roughness is feed and followed by nose radius. They also analyzed that the most significant parameter for MRR is DOC and followed by cutting speed.

Shreemoy Kumar Nayak, et al. [4] conducted experiments by using multi objective Grey relational analysis for optimization of cutting process parameters in dry turning of AISI 304 austenitic stainless steel, and machinability characteristics of material removal rate, cutting force and surface roughness were studied. Experiments were conducted as per Taguchi L27 orthogonal array. From the mean of the overall Grey relational grade it is concluded that feed has high significance on Material Removal Rate (MRR), cutting forces and Surface roughness together followed by speed and depth of cut has least significance.

DiptiKanta Das, et al. [5] have done investigations for finding the optimal combination of cutting process parameters during hard machining of EN 24 steel with coated carbide insert by using Grey based Taguchi(L9 orthogonal array) and Regression methodology for minimum Surface quality characteristics R_a and R_z. The results concluded that the feed is considered to be the most dominant parameter for both Surface Roughness parameters R_a and R_z. The prediction models have been developed using regression analysis for surface Roughness and they are adequate and significant.

M.P.Gang [6]. Conducted an investigation on machining characteristic of C34000 (medium brass alloy) material in CNC turning process using GC1035 Coated carbide tool. In this research paper focused on the analysis of optimum cutting conditions to get the maximum material removal rate in CNC turning of different grades of medium brass alloy material by Taguchi method. It has been found that ANOVA shown that the depth of cut has significant role to play in producing higher MRR.

Somashekara and Lakshmana [7] have studied the machining control factors considering cutting speed, feed rate and depth of cut in order to optimize surface roughness while machining aluminum alloy Al 6351-T6 using uncoated carbide tool. The optimization was carried out using Taguchi techniques and they concluded that speed has a major influence on the surface roughness of aluminum alloy.

C.J.Rao, et al. [8] investigated the influence of speed, feed, and depth of cut on Surface Roughness and Cutting forces during machining of AISI 1050 steels (hardness of 484HV) on CNC lathe with ceramic (Al2O3+TiC matrix) tool. The experiments were conducted by using Taguchi method (L27 design with 3 levels and 3 factors). The results indicated that feed rate has most influence on both Cutting forces as well as Surface Roughness. Depth of cut has a significant influence on Cutting force, but has an insignificant influence on Surface roughness. The interaction of feed and depth of cut and the interaction of all the three cutting parameters have significant influence on cutting forces, whereas none of the interaction effects are having significant influence on the Surface Roughness produced.

Sunil J Raykar, et al. [9] investigated on the effect of process parameters on R_a, R_z, R_q parameters of surface topology in dry machining of EN8 steel by using Taguchi L27 orthogonal array and Regression analysis. Results concluded that feed has greatest influence on surface finish of all three surface topology parameters R_a, R_q and R_z next is to cutting speed and depth of cut has least significance. Regression models were prepared and a good correlation is found between Surface Roughness and cutting parameters and hence the models were used for predict the Surface Roughness within the range of cutting parameters under investigation.

M. Kaladhar et al. [10] optimized multi-characteristics response for turning of AISI 202 austenitic stainless steel using a CVD coated cemented carbide tool on CNC TC based on Taguchi and Utility concept. They have used this concept for optimize process parameters such as speed, feed, depth of cut, and nose radius and selected multiple performance characteristics, namely, surface roughness and material removal rate. Taguchi’s L8 orthogonal array was selected for experimental planning. The experimental result analysis showed that the combination of higher levels of cutting speed, depth of cut, and nose radius and lower level of feed is essential to achieve simultaneous maximization of MRR and minimization of Ra. They have performed ANOVA for individual quality parameters as well as for multi response case. Based on the ANOVA, the most statistical significant and percent contribution of the process parameters for multiple performances were depth of cut, cutting speed whereas feed and nose radius were less effective.

B.Singarvel et al. [11] have done experimental analysis the optimum machining parameters were evaluated using Taguchi based utility concept coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools. This strategy has been utilized for simultaneous minimization of surface harshness, cutting power and maximization of material removal rate. They found that the results of ANOM shown that a combination of machining parameters for this investigation were cutting speed of 244 m/ min, feed rate of 0.10 mm/rev and depth of cut of 1.0 mm with CVD coated tool. The result of ANOVA showed that the coated tool was the most significant parameter followed by cutting speed. The prediction error (i.e) the difference between the predicted SN ratio and multi objective SN ratio was within the confidence level.

Hari Vasudevan et al. [12] studied a hybrid multi objective optimization algorithm involving utility and fuzzy coupled with Taguchi methodology. Four process parameters, at three levels were selected for the study viz. tool nose radius, cutting speed, feed and depth of cut and surface roughness, cutting force and material removal rate were chosen as quality performance measures. They used Taguchi L27 orthogonal array to perform experiments. Woven fabric based GFRP/Epoxy tubes produced using hand layup process were finish turned using Poly Crystalline Diamond (PCD) tool. Utility values of the three performance measures were transformed into a single Multi Performance Characteristics Index (MPCI) using Mamdani type fuzzy inference system. Then, MPCI is then optimized using Taguchi analysis. The for multi characteristics the optimal sequence found: tool nose radius of 0.8 mm, cutting speed of 200 m/min, feed rate of 0.05 mm/rev and depth of cut of 1mm. The confirmatory experiment at these settings gives maximum value of MPCI validating the results.

Kishan Choudhuri et al. [13] used Taguchi and Utility concept to optimize the process parameters, such as speed, feed, and depth of cut on multiple performance characteristics, namely surface roughness and material removal rate during turning of Aluminium 6061 using a Carbide cutting tool on CNC TC. Taguchi’s L9 orthogonal array was selected for experimental planning. The experimental result showed that combination of higher levels of feed, depth of cut, and lower level of spindle speed was essential to achieve simultaneous maximization of MRR and minimization of surface roughness. They have performed ANOVA analysis for individual response characteristic. From ANOVA analysis they found that the depth of cut (65.57%) was most significantly influences the Ra followed by spindle speed (6.344%) and in case of material removal rate, feed (76.109%) was the most significant parameter followed by spindle speed (9.597%).

Nithyanandhan T. et al. [14] have investigated the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of process parameters. And the analysis of Variance (ANOVA) is also used to analyze the influence of cutting parameters during machining. AISI 304 stainless steel work pieces are turned on conventional lathe by using tungsten carbide tool. The results revealed that the feed and nose radius is the most significant process parameters on work piece surface roughness. However, the depth of cut and feed are the significant factors on MRR.

Kompan Chomsamutr et al. [15] objective of research is to compare the cutting parameters of turning operation the work pieces of medium carbon steel (AISI 1045) by finding the longest tool life by Taguchi methods and Response Surface Methodology: RSM. This research is to test the collecting data by Taguchi method. The analyses of the impact among the factors are the depth of cut, cutting speed and feed rate. This research found that the most suitable response value; and tool life methods give the same suitable values, i.e. feed rate at 0.10 mm/rev, cutting speed at 150 m/min, and depth of cut at 0.5 mm, which is the value of longest tool life at 670.170 min, while the average error is by RSM at the percentage of 0.07 as relative to the testing value.

Sunil Kumar Sharma et al. [16] have analyzed that Taguchi optimization technique pair with grey relational analysis has been adopted for evaluating parametric complex to carry out acceptable surface roughness lower is better, material removal rate higher is better of the AISI 8620 steel during turning on a CNC Lathe Trainer. After identify the optimal process parameters setting for turning operation, ANOVA is also applied for finding the most significant factor during turning operation. In this study it is concluded that the feed rate is the most significant factor for the surface roughness and material removal rate together, as the P-value is less than 0.05. Cutting speed and depth of cut is found to be insignificant from the ANOVA study.

Tian-Syung Lan et al.[17] investigated the effect of cutting speed, feed, cutting depth, tool nose runoff with three levels (low, medium, high) on MRR in finish turning based on L9(34) orthogonal array. It have been found that the material removal rates from the fuzzy Taguchi deduction optimization parameters are all significantly advanced comparing to those from the benchmark. Also it has been declare that contributed the satisfactory fuzzy linguistic approach for the MRR in CNC turning with profound insight.

Ishwer Shivakoti et al.[18] presents a genetic algorithm optimization approach for finding the optimal parameter setting during turning operation in conventional Lathe machine. It was found that material removal rate in-creases with the increase of feed rate. However, at low spindle speed of rotation, the material removal rate is high compared to high spindle speed of rotation. The regression equation for material removal rate (MRR) has been developed using statistical Minitab software. The regression equation was validated through comparative results of MRR achieved during experimentation. Genetic Algorithm (GA) has been used to achieve the optimum machining parametric combination in order to obtain the value of optimal result of material removal rate. The results obtained in this paper can be effectively utilized for machining, particularly turning operation of mild steel material in shop floor manufacturing.

Jafar Zare and Afsari Ahmad [19] studied the performance characteristics in turning operations of D2 (1.2510) steel bars using TiN coated tools. Three cutting parameters namely, cutting speed, feed rate, and depth of cut, will be optimized with considerations of surface roughness. The study shows that the Taguchi method is suitable to solve the stated within minimum number of trials as compared with a full factorial design. The main objective of this study was to demonstrate a systematic procedure of using Taguchi design method in process control of turning process and to find a combination of turning parameters to achieve low material removal rate.

C.J.Rao, et al. [20] investigated the influence of speed, feed, and depth of cut on Surface Roughness and Cutting forces during machining of AISI 1050 steels (hardness of 484HV) on CNC lathe with ceramic (Al2O3+TiC matrix) tool. The experiments were conducted by using Taguchi method (L27 design with 3 levels and 3 factors). The results indicated that feed rate has most influence on both Cutting forces as well as Surface Roughness. Depth of cut has a significant influence on Cutting force, but has an insignificant influence on Surface roughness. The interaction of feed and depth of cut and the interaction of all the three cutting parameters have significant influence on cutting forces, whereas none of the interaction effects are having significant influence on the Surface Roughness produced.

Sunil J Raykar, et al. [21] investigated on the effect of process parameters on R_a, R_z, R_q parameters of surface topology in dry machining of EN8 steel by using Taguchi L27 orthogonal array and Regression analysis. Results concluded that feed has greatest influence on surface finish of all three surface topology parameters R_a, $R_q$and R_z next is to cutting speed and depth of cut has least significance. Regression models were prepared and a good correlation is found between Surface Roughness and cutting parameters and hence the models were used for predict the Surface Roughness within the range of cutting parameters under investigation.

Shreemoy Kumar Nayak, et al. [22] Conducted experiments by using multi objective Grey relational analysis for optimization of cutting process parameters in dry turning of AISI 304 austenitic stainless steel, and machinability characteristics of material removal rate, cutting force and surface roughness were studied. Experiments were conducted as per Taguchi L27 orthogonal array. From the mean of the overall Grey relational grade it is concluded that feed has high significance on Material Removal Rate (MRR), cutting forces and Surface roughness together followed by speed and depth of cut has least significance.

DiptiKanta Das et al. [23]Investigated for finding the optimal combination of cutting process parameters during hard machining of EN 24 steel with coated carbide insert by using Grey based Taguchi(L9 orthogonal array) and Regression methodology for minimum Surface quality characteristics R_a and R_z. The results concluded that the feed is considered to be the most dominant parameter for both Surface Roughness parameters R_a and R_z. The prediction models have been developed using regression analysis for surface Roughness and they are adequate and significant.

Bharat Chandra Routara et al. [24] had studied highlights a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study in CNC end milling of UNS C34000 medium leaded brass. Utility theory has been adopted to convert a multi-response optimization problem into a single response optimization problem; in which overall utility degree serves as the representative single objective function for optimization. They have been used combination of utility concept and Taguchi methodology for predicting optimal setting of process parameters. Finally the optimal setting has been verified by confirmation runs.

B.Singarvel et al. [25] had done experimental analysis the optimum machining parameters were evaluated using Taguchi based utility concept coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools. This strategy has been utilized for simultaneous minimization of surface harshness, cutting power and maximization of material removal rate. They found that • The results of ANOM shown that a combination of machining parameters for this investigation were cutting speed of 244 m/ min, feed rate of 0.10 mm/rev and depth of cut of 1.0 mm with CVD coated tool. The result of ANOVA showed that the coated tool was the most significant parameter followed by cutting speed. The prediction error (i.e) the difference between the predicted SN ratio and multi objective SN ratio was within the confidence level.

Hari Vasudevan et al. [26] had studied a hybrid multiobjective optimization algorithm involving utility and fuzzy coupled with Taguchi methodology. Four process parameters, at three levels were selected for the study viz. tool nose radius, cutting speed, feed and depth of cut and surface roughness, cutting force and material removal rate were chosen as quality performance measures. They used Taguchi L27 orthogonal array to perform experiments. Woven fabric based GFRP/Epoxy tubes produced using hand layup process were finish turned using Poly Crystalline Diamond (PCD) tool. Utility values of the three performance measures were transformed into a single Multi Performance Characteristics Index (MPCI) using Mamdani type fuzzy inference system. Then, MPCI is then optimized using Taguchi analysis. The for multi characteristics the optimal sequence found: tool nose radius of 0.8 mm, cutting speed of 200 m/min, feed rate of 0.05 mm/rev and depth of cut of 1mm. The confirmatory experiment at these settings gives maximum value of MPCI validating the results.

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R. Jayadithya et al. [28] have been conducted experiments using 3 machine parameters such as pulse on time (TON), pulse off time, wire feed and one work piece parameter such as work piece thickness, each at three levels for obtaining the responses like cutting speed, surface roughness, and dimensional deviation. Taguchi’s L9 orthogonal array was selected to collect information regarding the process with lesser number of experimental runs. Conventional Taguchi approach is insufficient to solve a multi response optimization problem. In order to overcome this limitation, utility theory has been applied. ANOVA analysis was also carried out to find out the significant effect of the process parameters during WEDM process. Finally confirmation test has been carried out to verify the experimental result.

RavinderKataria et al. [29] had compared different multiple response optimization techniques for turning operation of AISI O1 tool steel. They selected nose radius, speed, feed and depth of cut as input process parameters and material removal rate, surface roughness as quality parameters. Taguchi method was employed for single response optimization. For multi-response optimization, weighted signal-to-noise ratio (WSN), grey relational analysis (GRA), utility concept and technique for order preference by similarity to ideal solution (TOPSIS) method have been utilized and their performance was evaluated. The optimal process parameter settings for WSN, GRA, Utility Concept and TOPSIS were A1B3C2D3, A2B1C1D2, A2B3C3D2 and A2B2C3D3 respectively. Hence, there has been considerable difference among the optimal settings yielded by the methods investigated. Weighted signal-to-noise ratio method has been found to produce best results for multi-response optimization for this study.

Rina Chakravorty et al. [30] had studied the effect of process parameters such as work piece polarity, pulse-on-time, duty factor, open discharge voltage, discharge current, dielectric fluid on different quality parameters such as material removal rate and electrode wear rate in EDM process. The experimental results data of EDM processes were analyzed using the modified PCA-based UT approach and PCA -based PQLR method. The comparison of the optimization performances at the optimal conditions derived by the two methods indicates that the optimal condition derived by the modified PCA-based UT method leads to better optimization performance than PCA-based PQLR method. This suggests that the modified PCA-based UT approach can be a promising method for optimizing correlated responses of EDM process. TarunGoyal et al. [15] have used Utility theory and Taguchi quality loss function for simultaneous optimization of more than one response characteristics for low-pressure cold spray (LPCS) process to deposit copper coatings. They selected coating density and surface roughness as quality characteristics and feed type, substrate material, stagnation pressure, stagnation temperature, standoff distance taken as input process parameters. Utility values based upon these response parameters have been analyzed for optimization by using Taguchi approach. For the experiments they found that the selected quality parameters were significantly improved using Taguchi utility concept and analysis of variance also performed to analyzethe parameters are significantly effect on multi responding parameters.

Yogendra Kumar et al. [31] had performed multi- response optimization in dry turning process using Taguchi and utility concept. They selected nose radius, cutting speed, feed rate and depth of cut as input process parameters and axial force, radial force, main cutting force, material removal rate as quality parameters. They have selected EN47 alloy steel as work material and experiments were performed based on mixed L18 Taguchi orthogonal array. They found that all the four process parameters, namely, nose radius, cutting speed, feed and DOC had significant effect on utility function for multi optimization. The model can be used for optimization of multi-response characteristics that have realistic data.

Nithyanandhan T. et al. [32] have investigated the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of process parameters. And the analysis of Variance (ANOVA) is also used to analyze the influence of cutting parameters during machining. AISI 304 stainless steel work pieces are turned on conventional lathe by using tungsten carbide tool. The results revealed that the feed and nose radius is the most significant process parameters on work piece surface roughness. However, the depth of cut and feed are the significant factors on MRR.

D. Philip Selvaraj et al. [33] have studied the Taguchi optimization method was applied to find the optimal process parameters, which minimizes the surface roughness during the dry turning of AISI 304 Austenitic Stainless Steel. A Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters. ANOVA results shows that feed rate, cutting speed and depth of cut affects the surface roughness by 51.84%, 41.99% and 1.66% respectively. A confirmation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

Samruddhi Rao et al. [34] presented a detailed overview of Taguchi Method in terms of its evolution, concept, steps involved and its interdisciplinary applications. It could be concluded that this method with its perfect amalgamation of statistical and quality control techniques was one of the effective and efficient methods of its kind to highlight the benefits of designing quality into products upstream rather than inspecting out bad products downstream. It offers a quantitative solution to identify design factorsto optimize quality and reduce cost. Also the application of this method is not confined to a particular domain but also to other fields like product and service sectors. It thus is a powerful method as compared to the other intuitive and more cumbersome methods encompassing a large number of fields in terms of application.

M. Adinarayana et al. [35] have presented in paper the multi response optimization of turning parameters for Turning on AISI 4340 Alloy Steel. Experiments are designed and conducted based on Taguchi's L27 Orthogonal array design. This paper discusses an investigation into the use of Taguchi parameter Design and Regression analysis to predict and optimize the Surface Roughness, Metal Removal Rate and Power Consumption in turning operations using CVD Cutting Tool. The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning. This paper also remarks the advantages of multi-objective optimization approach over the single-objective one. The useful results have been obtained by this research for other similar type of studies and can be helpful for further research works on the Tool life and Vibration of tools etc.

KompanChomsamutr et al. [36] objective of research is to compare the cutting parameters of turning operation the work pieces of medium carbon steel (AISI 1045) by finding the longest tool life by Taguchi methods and Response Surface Methodology: RSM. This research is to test the collecting data by Taguchi method. The analyses of the impact among the factors are the depth of cut, cutting speed and feed rate. This research found that the most suitable response value; and tool life methods give the same suitable values, i.e. feed rate at 0.10 mm/rev, cutting speed at 150 m/min, and depth of cut at 0.5 mm, which is the value of longest tool life at 670.170 min, while the average error is by RSM at the percentage of 0.07 as relative to the testing value.

Sunil Kumar Sharma et al. [37] have analyzed that Taguchi optimization technique pair with grey relational analysis has been adopted for evaluating parametric complex to carry out acceptable surface roughness lower is better, material removal rate higher is better of the AISI 8620 steel during turning on a CNC Lathe Trainer. After identify the optimal process parameters setting for turning operation, ANOVA is also applied for finding the most significant factor during turning operation. In this study it is concluded that the feed rate is the most significant factor for the surface roughness and material removal rate together, as the P-value is less than 0.05. Cutting speed and depth of cut is found to be insignificant from the ANOVA study.

From the above literature review, it has been observed that no much work is reported on Multi objective optimization of Material Removal Rate (MRR) and Surface Roughness (R_a) characteristics in turning of SS304 with a coated tungsten carbide tools. Also very less works are there by considering the nose radius as one of the controlling parameter. In the present investigation, Multi objective optimization of responses was done using Taguchi based utility and AHP methods. The optimal combination of machining parameters (cutting speed, feed, depth of cut and nose radius) in order to attain the maximum Material Removal Rate and minimum Surface Roughness simultaneously has been obtained.

CHAPTER-3
METHODOLOGY

3.1. Desirability function analysis

DFA is a prominent method employed in industries to optimize multiple response processes. It was first proposed by Harrington and popularized by Derringer and Suich as a technique for simultaneous optimization of multiple responses. It is widely accepted and used in industries and academic area. The application of DFA for multi response optimization is reported by many authors in various machining processes such as end milling of Inconel 718 alloy, EDM of Inconel 718, end milling of GFRP composites and turning of GFRP composites etc.

In DFA, a product (or process) having multiple quality characteristics is unacceptable if any of them is outside some desired limits. It aims to obtain a set of cutting conditions that result in most desirable response values. All the response values are transformed to lie in the range 0 to 1 and individual desirability index is evaluated. The composite desirability index is then determined as weighted geometric mean for each pair of response variables. The parameter settings with maximum composite desirability are considered as optimum cutting conditions that yield most desirable values for all the responses under consideration. The process of optimization using DFA involves the following steps.

Step 1: Each response is assigned a number between 0 and 1 using appropriate desirability function. The assigned values are called individual desirability index (*d_i*) with “0” indicating completely undesirable value of the response while “1” indicates completely desirable or ideal value of the response. Three types of desirability functions can be used to transform the response to a common scale [0 1] based on whether response is maximization, minimization or hitting a target type.

Let y_{min}, y_{max} and y_{tar} be the lower, upper and target values respectively for the response y_i such that $y_{min} \le y_{tar} \le y_{max}$; d_i is the individual desirability index. For quality characteristic of nominal-the-best type, the desirability function given in Eq.1 can be used to determine individual desirability index.

$$d_i = \begin{cases} \left(\frac{y_i - y_{min}}{y_{tar} - y_{min}}\right)^s, y_{min} \le y_i \le y_{tar}, \ s \ge 0 \\ \left(\frac{y_i - y_{max}}{y_{tar} - y_{max}}\right)^t, y_{tar} \le y_i \le y_{max}, \ t \ge 0 \\ 0 \qquad\qquad otherwise \end{cases} \quad \text{………………. Eq.(1)}$$

In this case, it is desired to obtain the target value y_{tar} for each of the response y_i. When y_i equals to y_{tar}, $d_i = 1$ and is the most desirable value. As the value of y_i deviates from y_{tar}, d_i value decreases and becomes equal to “0” and is unacceptable. For all other conditions, d_i lies between 0 and 1.

For quality characteristic of larger-the-better type, the desirability function given in Eq.2or Eq.3 can be used to determine individual desirability index. This is used when the response is to be maximized

$$d_i = \begin{cases} 0 & y_i < y_{min} \\ \left(\frac{y_i - y_{min}}{y_{tar} - y_{min}}\right)^r & , y_{min} \leq y_i \leq y_{tar}, r \geq 0 \\ 1 & y_i > y_{tar} \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.(2)}$$

Here, y_{tar} is considered as largest value for the response y_i i.e. $y_{tar}=y_{max}$. Hence, Eq.2 can be rewritten as

$$d_i = \begin{cases} 0 & y_i < y_{min} \\ \left(\frac{y_i - y_{min}}{y_{max} - y_{min}}\right)^r & , y_{min} \leq y_i \leq y_{max}, r \geq 0 \\ 1 & y_i > y_{max} \end{cases} \ldots\ldots\ldots\ldots\ldots. Eq.(3)$$

In this case, when y_i is greater than y_{max} desirability requirement is achieved and di becomes equal to 1. The value of d_i to “0” when y_i is less than y_{min} and is treated as undesirable condition. For all other conditions, d_i values are obtained in the range 0 to 1.

For quality characteristic of smaller-the-better type, the desirability function given in Eq.4 or Eq.5 can be used to determine individual desirability index. This is used when the response is to be minimized.

$$d_i = \begin{cases} 1 & y_i < y_{tar} \\ \left(\frac{y_i - y_{max}}{y_{tar} - y_{max}}\right)^r & , y_{tar} \leq y_i \leq y_{max}, r \geq 0 \\ 0 & y_i > y_{max} \end{cases} \ldots\ldots\ldots\ldots. Eq.(4)$$

Here, y_{tar} is treated as smallest value for the response y_i i.e. $y_{tar} = y_{min}$. Hence, Eq.4 can be rewritten as

$$d_i = \begin{cases} 1 & y_i < y_{min} \\ \left(\frac{y_i - y_{max}}{y_{min} - y_{max}}\right)^r & , y_{min} \leq y_i \leq y_{max}, r \geq 0 \\ 0 & y_i > y_{max} \end{cases} \ldots\ldots\ldots\ldots. Eq.(5)$$

Here, d_i becomes equal to 1 when y_i is less than y_{min} and is the most desirable situation. As y_i deviates from y_{min}, d_i value decreases and equals to “0” when y_i exceeds y_{max}. For all other values of y_i, the values of di are obtained in the range [0 1]. The exponents s, t and r in the Eq. 1-5, represent the weights assigned to respective response variable according to the requirement of user. Generally, weights are decided based on the importance of quality characteristic.

Step 2: In this step, the CD is evaluated taking the geometric mean of individual desirability index obtained in the step 1. The CD is also known as overall desirability or total desirability and is expressed as in Eq. 6.

$$CD = \sqrt[w]{d_1^{w_1}\ x\ d_2^{w_2}\ x\ d_3^{w_3} \ldots\ldots\ldots.d_k^{w_k}} \ldots\ldots\ldots\ \text{Eq.(6)}$$

Where, k is the number of responses, d_i is the individual desirability, w_i is the weight assigned to the i^{th} response, $w = \sum_i^k wi = 1$. If any of the responses is completely unacceptable i.e., $d_i = 0$ then composite desirability also becomes zero.

Step 3: The next step is to determine the optimum cutting conditions. The parameters settings giving the highest composite desirability are preferred and are considered as optimal cutting conditions.

Step 4: Perform ANOVA for CD to evaluate relative significance of the process variables on combined objective.

Step 5: The last step is to predict the response variables at optimal parameter settings and validate the result.

3.2. Grey Relational Analysis (GRA)

In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one this process is known as grey relational generation. Next, based on the normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple- response- process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade using Taguchi Analysis.

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{Eq.(7)}$$

For higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{Eq.(8)}$$

Where, $x_i(k)$ is the value after the grey relational generation. Min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. An ideal sequence is $x_0(k)$ for the response. The purpose of grey relational grade is to reveal the degree of relation between the sequences. The grey relational coefficient ξ (k) can be calculated as:

$$\xi(k) = \frac{\Delta_{min} + \theta\,\Delta_{max}}{\Delta_{0i}(k) + \theta\,\Delta_{max}} \text{..Eq.(9)}$$

Where, $\Delta_{0i} = \|x_o(k) - x_i(k)\|$ = difference of the absolute value $x_o(k)$ and $x_i(k)$.

θ is the distinguishing coefficient $0 \le \theta \le 1$.

Δ_{min} is the smallest value of Δ_{oi}

Δ_{max} is the largest value of Δ_{oi}

After averaging the grey relational coefficients, the grey relational grade γ_i can be computed as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \text{..Eq.(10)}$$

Where, n = number of process responses. The higher value of grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal. However, in the above equation assumes that all response features are equally important. But, in practical case, it may not be so. Therefore, different weightages have been assigned to different response features according to their relative priority. In that case, the equation for calculating overall grey relational grade (with different weightages for different responses) is modified as shown below:

$$\gamma_i = \frac{\sum_{k=1}^{n} w_k \xi_i(k)}{\sum_{k=1}^{n} w_k} \text{..Eq.(11)}$$

Here, γ_i is the overall grey relational grade for i^{th} experiment. $\xi_i(k)$ is the grey relational coefficient of k^{th} response in i^{th} experiment and w_k is the weightage assigned to the k^{th} response.

CHAPTER 4
EXPERIMENTAL DETAILS

The experimental steps involved in the present work are clearly explained in this chapter. This includes selection of work material, selection of process parameters with their levels and selection of appropriate orthogonal array etc.

4.1. Selection of Work Material

The work material selected for the study is stainless steel of grade SS304. The work specimens are of cylindrical shape are taken and shown in figure 4.1. The work material has a wide range of applications in Heat exchangers, springs, food processing equipments, threaded fasteners, architectural paneling etc. The chemical and mechanical properties of SS304 are given in the tables 4.1and 4.2.

Fig 4.1. SS304 Material

Table 4.1. Chemical Composition of SS304 Steel

Element	C	Mn	Si	P	S	Cr	Ni	N	Fe
Max.	0.08	2	0.75	0.045	0.03	20	10.5	0.10	Remining

Table 4.2. Mechanical Properties of SS304 Steel

Density (Kg/m^3)	Tensile strength (MPa) min	Yield Strength 0.2% proof (MPa) min	Elongation (% in 50mm) min	Poisson's ratio	Hardness (RHN) (HR B) Max	Hardness (BHN) max
8000	515	205	40	0.27-0.30	92	201

4.2. Selection of the Process Parameters and Their Levels

Selection of right combination of process parameters and setting the range of the process parameters is very important step in unconventional process. Small variation in process parameters will effect adversely on the Surface Roughness and accuracy of the machined components. In general, the process parameters are of two types.

- Fixed parameters
- Controlled parameters

In this present work the tool geometry, work piece hardness and its mechanical properties and environmental conditions are taken as fixed parameters which will not be changed throughout the investigation, whereas cutting speed, feed depth of cut and nose radius are considered as the controlled parameters are used to change for each experiment by Taguchi approach. The selected process parameters for the experiment with their limits, notations and units are given in table 4.3.

Table 4.3. Process Parameters and Their Levels

Factor Notation	Parameter	Levels		
		1	2	3
A	Nose Radius (mm)	0.4	0.8	-

B	Speed (m/min)	45	60	75
C	Feed (mm/rev)	0.05	0.1	0.15
D	Depth of cut (mm)	0.5	1.0	1.5

4.3. Selection of Orthogonal Array (OA)

Taguchi has developed a design called orthogonal array it is used to study the entire design space with a very less number of experiments. For the four parameters with mixed levels taguchi’s standard L18 has been chosen and it is given in the table 4.4.

Table 4.4. Taguchi L18 Orthogonal Array

S. No	Nose radius r(mm)	Cutting speed N(m/min)	Feed f(mm/rev)	Depth of cut d(mm)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2

14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

The experiments were conducted on CNC turret lathe it is shown in the figure 4.2. The work pieces are first trued for 0.5 mm to remove the unevenness and the components after machining were shown in the figure 4.3. After machining the finished components were tested for their roughness with SJ-210 tester shown in the figure 4.4.

Figure 4.2 .CNC Machine

.

Figure 4.3. Machined Components

Figure 4.4. SJ-210 Roughness Tester

CHAPTER 5

RESULTS & DISCUSSIONS

In this chapter the experimental results of material removal rate (MRR) and surface roughness R_a are analyzed using Desirability-Grey Analysis. The focus of the work is to identify the optimal combination of process parameters that concurrently maximizes the material removal rate and minimizes the surface roughness characteristics.

5.1. Experimental Results

The measured results of both material removal rate and surface roughness were tabulated in table 5.1. The responses were first transformed to lie in the range 0 to 1 and individual desirability index is calculated using appropriate desirability function as discussed in methodology. The results of individual desirability's of responses were mentioned in table 5.2.

Table 5.1. Experimental Results

S. No	MRR (cm^3/min)	R_a (μm)
1	0.225	2.441
2	4.5	1.894
3	10.125	2.573
4	1.5	1.672
5	6	1.579
6	13.5	2.998
7	3.75	2.9
8	11.25	1.556
9	5.625	2.134
10	3.375	1.792
11	2.25	2.104
12	6.75	0.856
13	3	2.207

14	9	1.956
15	4.5	1.15
16	5.625	1.328
17	3.75	1.783
18	11.25	4.9

Table 5.2. Individual desirability (d_r) values of responses

S.N0.	d_r	
	MRR (cm^3/min)	R_a (µm)
1	0	0.6081
2	0.3220	0.7433
3	0.7458	0.5754
4	0.0960	0.7982
5	0.4350	0.8212
6	1	0.4703
7	0.2655	0.4946
8	0.8305	0.8269
9	0.4068	0.6840
10	0.2373	0.7685
11	0.1525	0.6914
12	0.4915	1
13	0.2090	0.6659
14	0.6610	0.7280

15	0.3220	0.9273
16	0.4068	0.8833
17	0.2655	0.7708
18	0.8305	0

For the individual desirability's obtained the deviations from the target values are designed and depicted in table 5.3

Table 5.3. Deviation values of responses

S.No.	Δoi	
	MRR (cm^3/min)	R_a (µm)
1	1	0.3919
2	0.6780	0.2567
3	0.2542	0.4246
4	0.9040	0.2018
5	0.5650	0.1788
6	0	0.5297
7	0.7345	0.5054
8	0.1695	0.1731
9	0.5932	0.3160
10	0.7627	0.2315
11	0.8475	0.3086
12	0.5085	0
13	0.7910	0.3341
14	0.3390	0.2720

15	0.6780	0.0727
16	0.5932	0.1167
17	0.7345	0.2292
18	0.1695	1

Next step is to find the Grey relational coefficients and Grades for the individual experiments by considering distinguishing coefficient ɗ as 0.5. The obtained GRC and GRG values are given in tables 5.4 and 5.5 respectively finally the Ranking from the experiment was given in the descending order of overall GRG values

Table 5.4. Grey Relational Coefficient (GRC) values of responses

S.No.	GRC	
	MRR (cm3/min)	Ra (µm)
1	0.3333	0.5606
2	0.4245	0.6608
3	0.6629	0.5408
4	0.3561	0.7125
5	0.4695	0.7366
6	1	0.4856
7	0.4050	0.4973
8	0.7468	0.7428
9	0.4574	0.6127
10	0.3960	0.6836
11	0.3711	0.6183
12	0.4958	1
13	0.3873	0.5995
14	0.5960	0.6477

15	0.4245	0.8731
16	0.4574	0.8107
17	0.4050	0.6857
18	0.7468	0.3333

Table 5.5. Grey Relation Grade Values

S.No.	GRG	Rank
1	0.4470	18
2	0.5426	10
3	0.6019	8
4	0.5343	14
5	0.6030	7
6	0.7428	3
7	0.4512	17
8	0.7448	2
9	0.5350	13
10	0.5398	12
11	0.4947	15
12	0.7479	1
13	0.4934	16
14	0.6218	6
15	0.6488	4
16	0.6340	5
17	0.5454	9

18	0.5401	11

5.2 . Response Surface Methodology (RSM)

The Response Surface Methodology was employed on the multiple response value of GRG for knowing the significance of process parameters. The model designed is given in equation 5.1. ANOVA results obtained are depicted in table 5.6. Results showing that feed and depth of cut have a significant effect on the Multi-Response. The pareto and residual plots were drawn and shown in figures 5.1 and 5.2 respectively. From the figures it can be concluded that the model designed is best fit and accurate.

RSM Results

$$\begin{aligned} GRG = & -0.330 + 0.067\, r + 0.0256\, N + 4.03\, f - 0.400\, d - 0.000190\, N*N \\ & - 3.6\, f*f + 0.175\, d*d \\ & - 0.0043\, r*N + 1.70\, r*f + 0.008\, r*d - 0.0389\, N*f \\ & + 0.00379\, N*d - 0.65\, f*d \end{aligned}$$

Table 5.6 ANOVA Results

Source	DF	Adj SS	Adj MS	F	P
Model	13	0.113014	0.008693	0.91	0.602
Linear	4	0.067073	0.016768	1.76	0.299
r	1	0.000041	0.000041	0.00	0.951
N	1	0.000052	0.000052	0.01	0.945
f	1	0.031924	0.031924	3.35	0.141
d	1	0.023651	0.023651	2.48	0.191
Square	3	0.013019	0.004340	0.45	0.728
N*N	1	0.006783	0.006783	0.71	0.447
f*f	1	0.000272	0.000272	0.03	0.874
d*d	1	0.006373	0.006373	0.67	0.460
2-Way	6	0.020906	0.003484	0.37	0.870

Interaction					
r*N	1	0.001593	0.001593	0.17	0.704
r*f	1	0.001700	0.001700	0.18	0.695
r*d	1	0.000004	0.000004	0.00	0.985
N*f	1	0.004890	0.004890	0.51	0.514
N*d	1	0.004627	0.004627	0.48	0.525
f*d	1	0.000867	0.000867	0.09	0.778
Error	4	0.038171	0.009543		
Total	17	0.151185			

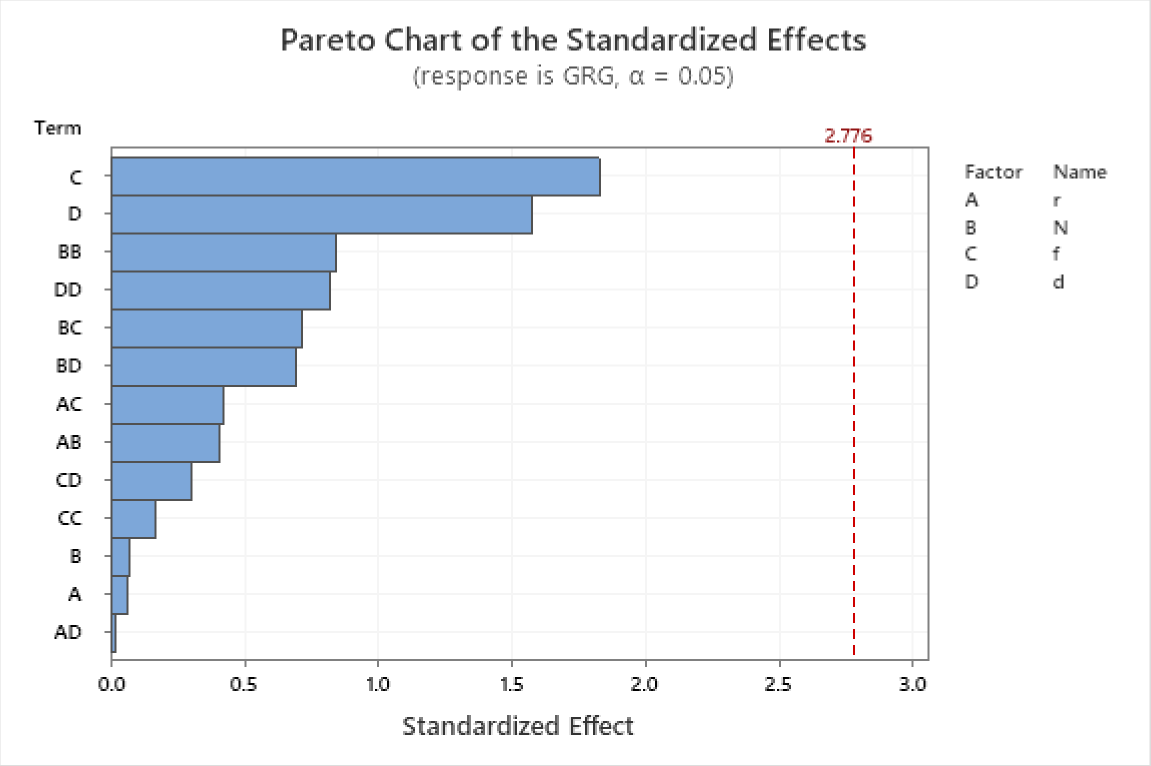

Figure 5.1. Pareto Chart for GRG

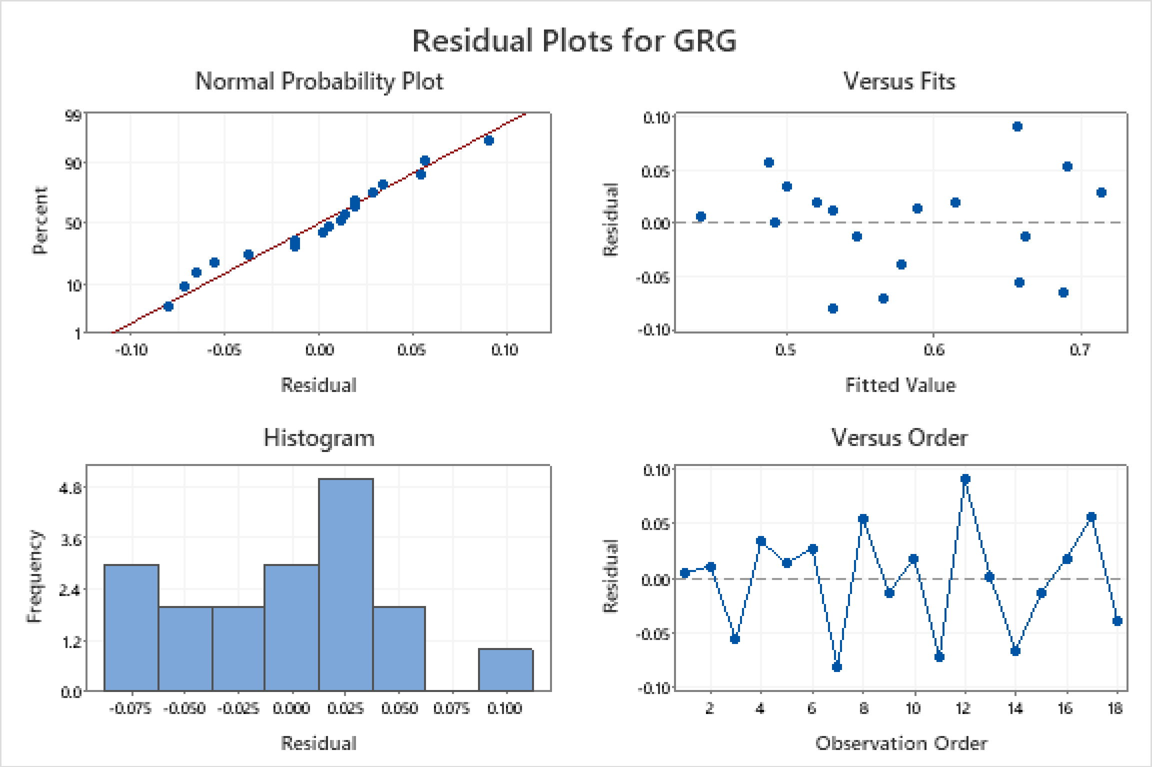

Figure 5.2. Residual plots for GRG

CHAPTER 6
CONCLUSIONS

From the experimental and Desirability based grey analysis results the following conclusions can be drawn

1. From the Desirability based grey analysis , the optimal condition of process parameters is obtained at

Nose radius : Level-2 ; 0.8mm

Cutting speed : Level-1 ; 45m/min

Feed : Level-3 ; 0.15mm/rev

Depth of cut : Level-2 ; 1.0mm

2.The results of ANOVA showed that the feed has the highest influence among the process parameters

3. From the results of residual plots, it is concluded that the errors are following the normality and constant variance hence the model prepared is best fit and more accurate for the prediction of responses.

4. The multi objective optimization of Desirability based grey analysis showed good results and they are validated through the model. Hence the proposed methodology can be effectively employed for the any industrial optimization problems where decision making is critical.

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