

**IMPROVEMENT OF SURFACE PROPERTIES IN MILLING OF DRNC  
(DISCONTINUOUSLY REINFORCED NYLON COMPOSITE) USING  
PRESSURIZED STEAM JET APPROACH**

*A thesis report submitted in partial fulfilment of  
the requirement for the award of the degree of*

**MASTER OF ENGINEERING  
(PRODUCTION AND INDUSTRIAL ENGINEERING)**

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CERTIFICATE

This is to certify that the thesis entitled "IMPROVEMENT OF SURFACE PROPERTIES IN MILLING OF DRNC (DISCONTINUOUSLY REINFORCED NYLON COMPOSITE) USING PRESSURIZED STEAM JET APPROACH" is authentic record of my study carried out as requirement for the award of the degree of **Master of Engineering (Production & Industrial Engineering)** to **Thapar University, Patiala**, under the guidance of **Dr. VINOD KUMAR SINGLA** (Associate Professor), Department of Mechanical Engineering, Thapar University, Patiala. This matter embodied in this thesis has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to be certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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Lastly, and most importantly, I wish to thank my parents. They supported me and loved me.

To them I dedicate this thesis.

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## Abstract

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A milling machine is a machine tool used to machine solid materials and it is conventional machining process. In the field of material science has been directed towards the development of new lightweight, high performance engineering materials like composites. In this study while milling, efforts are made to improve the surface properties of discontinuously reinforced nylon composite (DRNC) using pressurized steam jet approach. Steam jet act as transportation carriers carrying the heat away from the cutting region, and the efficiency of this cooling method largely depends on the jet pressure. The effect of feed rate, cutting speed, steam pressure and depth of cut on surface properties would be examined. For this study concept of Design of experiment has been used. Results has been evaluated with the help of Minitab software.

## ABBREVIATIONS

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<b><i>ANOVA</i></b>	<i>Analysis of Variance</i>
<b><i>DOF</i></b>	<i>Degree of Freedom</i>
<b><i>DRNC</i></b>	<i>Discontinuously Reinforced Nylon Composite</i>
<b><i>MRR</i></b>	<i>Material Removal Rate</i>
<b><i>SR</i></b>	<i>Surface Roughness</i>
<b><i>SH</i></b>	<i>Surface Hardness</i>
<b><i>S/N Ratio</i></b>	<i>Signal to Noise Ratio</i>

## NOTATIONS

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<i>OA</i>	<i>Orthogonal array</i>
<i>A</i>	<i>Steam Pressure</i>
<i>B</i>	<i>Cutting Speed</i>
<i>C</i>	<i>Feed Rate</i>
<i>D</i>	<i>Depth of Cut</i>
<i>SS</i>	<i>Sum of squares</i>
<i>SS'</i>	<i>Pure sum of square</i>

## *LIST OF FIGURES*

---

---

<i>FIGURE NO.</i>	<i>CAPTION</i>	<i>PAGE NO.</i>
<i>Fig 1.1</i>	<i>Cutting principle</i>	<i>12</i>
<i>Fig 1.2</i>	<i>Types of peripheral milling</i>	<i>13</i>
<i>Fig 1.3</i>	<i>Types of face milling</i>	<i>15</i>
<i>Fig 1.4</i>	<i>Column and knee type milling machine</i>	<i>17</i>
<i>Fig 1.5</i>	<i>Fixed bed type milling machine</i>	<i>18</i>
<i>Fig 3.1</i>	<i>L18 Linear graph</i>	<i>33</i>
<i>Fig 3.2</i>	<i>Vertical milling machine</i>	<i>35</i>
<i>Fig 3.3</i>	<i>Steam generator with pressure gauge</i>	<i>36</i>
<i>Fig 3.4</i>	<i>Profile of surface roughness</i>	<i>37</i>
<i>Fig 3.5</i>	<i>Experimental device for measurement of surface roughness</i>	<i>38</i>
<i>Fig 3.6</i>	<i>Experimental device for measurement of Surface hardness</i>	<i>39</i>
<i>Fig 3.7</i>	<i>Experimental design</i>	<i>40</i>
<i>Fig 3.8</i>	<i>Taguchi design procedure</i>	<i>42</i>
<i>Fig 3.9</i>	<i>Tool used for machining</i>	<i>45</i>
<i>Fig 3.10</i>	<i>Work piece after machining</i>	<i>45</i>
<i>Fig 4.1</i>	<i>Main effect plot of MRR for mean</i>	<i>50</i>
<i>Fig 4.2</i>	<i>Interaction plot for MRR for mean</i>	<i>50</i>
<i>Fig 4.3</i>	<i>Main effect plot of MRR of S/N ratio</i>	<i>53</i>
<i>Fig 4.4</i>	<i>Interaction plot for MRR of S/N ratio</i>	<i>53</i>
<i>Fig 5.1</i>	<i>Profile of surface roughness of experiment no. 9</i>	<i>58</i>
<i>Fig 5.2</i>	<i>Main effect plot for surface roughness of mean</i>	<i>61</i>
<i>Fig 5.3</i>	<i>Interaction plot surface roughness of mean</i>	<i>61</i>
<i>Fig 5.4</i>	<i>Main effect plot for surface roughness of S/N ratio</i>	<i>64</i>
<i>Fig 5.5</i>	<i>Interaction plot surface roughness of S/N ratio</i>	<i>64</i>
<i>Fig 6.1</i>	<i>Main effect plot for mean hardness</i>	<i>71</i>
<i>Fig 6.2</i>	<i>Interaction plot for mean hardness</i>	<i>71</i>
<i>Fig 6.3</i>	<i>Main effect plot for S/N ratio</i>	<i>74</i>
<i>Fig 6.4</i>	<i>Interaction plot for S/N ratio of hardness</i>	<i>74</i>

## **LIST OF TABLES**

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<b>TABLE NO.</b>	<b>CAPTION</b>	<b>PAGE NO</b>
3.1	<i>Factors and their levels of interest</i>	32
3.2	<i>Degree of freedom</i>	32
3.3	<i>L18 Experimental design</i>	34
3.4	<i>Response Characteristics</i>	43
4.1	<i>Results for MRR</i>	47
4.2	<i>Analysis of Variance for Means</i>	49
4.3	<i>Response Table for Means of MRR</i>	49
4.4	<i>Analysis of variance for S/N ratio of MRR</i>	52
4.5	<i>Response table for S/N ratio of MRR</i>	52
4.6	<i>Significant factors and interactions for MRR</i>	54
5.1	<i>Results for Surface Roughness (Ra)</i>	57
5.2	<i>Analysis of Variance for Roughness of Means</i>	60
5.3	<i>Response table for roughness of mean</i>	60
5.4	<i>Analysis of Variance for S/N ratio for roughness (Ra)</i>	63
5.5	<i>Response Table for S/N Ratios for roughness (Ra)</i>	63
5.6	<i>Significant factors and interactions for surface roughness</i>	66
6.1	<i>Result for surface hardness</i>	68
6.2	<i>ANOVA for mean of hardness</i>	70
6.3	<i>Response table for means of hardness</i>	70
6.4	<i>ANOVA for S/N ratio of hardness</i>	73
6.5	<i>Response table for means of hardness</i>	73
6.6	<i>Significant factors and interactions for hardness</i>	75

## TABLE OF CONTENTS

<i>Chapter</i>	<i>Title</i>	<i>Page No.</i>
	<i>CERTIFICATE</i>	2
	<i>ACKNOWLEDGEMENT</i>	3
	<i>ABSTRACT</i>	4
	<i>ABBREVIATIONS</i>	5
	<i>NOTATIONS</i>	6
	<i>LIST OF FIGURES</i>	7
	<i>LIST OF TABLES</i>	8
1.	<i>INTRODUCTION</i>	11-22
	<i>1.1 Milling operation</i>	11
	<i>1.2 Milling machine</i>	11
	<i>1.3 Cutting principle</i>	12
	<i>1.4 Types of milling operation</i>	13
	<i>1.5 Types of milling machine</i>	15
	<i>1.6 Construction of milling machine</i>	19
	<i>1.7 Milling process parameters</i>	20
	<i>1.8 Cutting parameters</i>	21
2.	<i>LITERATURE REVIEW</i>	23-30
	<i>2.1 Introduction</i>	23
	<i>2.2 Literature review</i>	23
3.	<i>METHODOLOGY</i>	31-45
	<i>3.1 Objective of present work</i>	31
	<i>3.2 Degree of freedom</i>	31
	<i>3.3 Selection of factors</i>	31
	<i>3.4 Orthogonal array</i>	32
	<i>3.5 Experimental setup</i>	34
	<i>3.6 Specification of vertical milling machine</i>	36
	<i>3.7 Measurement and test equipment</i>	37
	<i>3.8 Taguchi methodology</i>	39
4.	<i>EXPERIMENTAL RESULT AND ANALYSIS OF MRR</i>	46-55
	<i>4.1 Introduction</i>	46
	<i>4.2 Result for MRR</i>	46
	<i>4.3 Analysis of variance-MRR</i>	48
	<i>4.4 Result for S/N ratio-MRR</i>	51
	<i>4.5 Optimal design</i>	54
5.	<i>EXPERIMENTAL RESULT AND ANALYSIS OF SURFACE ROUGHNESS</i>	56-66
	<i>5.1 Introduction</i>	56
	<i>5.2 Result for surface roughness</i>	56
	<i>5.3 Analysis of variance for surface roughness</i>	59
	<i>5.4 Results for S/N ratio for surface roughness</i>	62
	<i>5.5 Optimal design</i>	64
6	<i>EXPERIMENTAL RESULT AND ANALYSIS OF SURFACE HARDNESS</i>	67-76
	<i>6.1 Introduction</i>	67

	<i>6.2 Results for surface hardness</i>	<i>67</i>
	<i>6.3 Analysis of variance for harness</i>	<i>69</i>
	<i>6.4 Results for S/N ratio</i>	<i>72</i>
	<i>6.5 Optimal design</i>	<i>75</i>
<i>7.</i>	<b>MULTIPLE REGRESSION ANALYSIS</b>	<i>77-78</i>
	<i>7.1 Introduction</i>	<i>77</i>
<i>8.</i>	<b>RESULTS AND CONCLUSION</b>	<i>79-81</i>
	<i>8.1.1 MRR</i>	<i>79</i>
	<i>8.1.2 Surface roughness</i>	<i>79</i>
	<i>8.1.3 Surface hardness</i>	<i>80</i>
	<i>8.2 Conclusions</i>	<i>80</i>
	<i>8.3 Scope for future work</i>	<i>81</i>
	<b>REFERENCES</b>	<i>82-84</i>
	<b>APPENDIX</b>	<i>85</i>

# CHAPTER 1

## INTRODUCTION

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### 1.1 INTRODUCTION TO MILLING OPERATION

Milling is one of the important machining operations. In this operation the work piece is fed against a rotating cylindrical tool. The rotating tool consists of multiple cutting edges (multipoint cutting tool). Normally axis of rotation of feed given to the work piece. Milling operation is distinguished from other machining operations on the basis of orientation between the tool axis and the feed direction, however, in other operations like drilling, turning, etc. the tool is fed in the direction parallel to axis of rotation. The cutting tool used in milling operation is called milling cutter, which consists of multiple edges called teeth. The machine tool that performs the milling operations by producing required relative motion between work piece and tool is called milling machine. It provides the required relative motion under very controlled conditions. These conditions will be discussed later in this unit as milling speed, feed rate and depth of cut.

Normally, the milling operation creates plane surfaces. Other geometries can also be created by milling machine. Milling operation is considered an interrupted cutting operation teeth of milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to bear the above stated conditions. Depending upon the positioning of the tool and work piece the milling operation can be classified into different types.

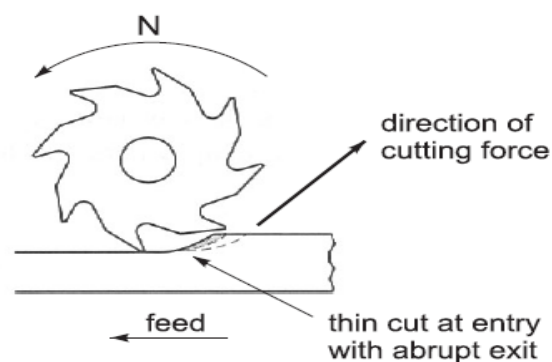
### 1.2 MILLING MACHINE

Milling machine were first invented by Eli Whitney to mass produce interchangeable musket parts. Developments and improvements of the milling machine and components continued, which results in the manufacturing of heavier arbors and high speed steels and carbide cutters. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines. Variations of milling machines were also developed to alleviate errors and provide better quality in the finished product. Milling is the process of removing material from the work piece by

moving the work piece (fixed to the table/bed) past a fixed position, rotating multi or single tooth milling cutter. The cutting action of teeth around the center axis of the milling cutter provides a fastest and accurate approach to milling. The machined surface may be flat, angular, or a multi dimensional curve or curve surface. The adjoining surfaces or edges may also be milled to produce any combination of shapes and contours. The machine used for these applications is properly referred to as a milling machine tool or a machining center.

### 1.3 CUTTING PRINCIPLE

Working of a milling machine is based on the fact that milling cutter is fed against work piece. This is achieved by developing relative motion with precise control between work piece and rotating milling cutter. Feed motion is generally given to the work piece through its holding device. Cutting mechanism of the work piece in milling operations is same as that in turning operation on lathe. This cutting takes place due to plastic deformation of metal by the cutting tool. Milling machine can also hold more than one cutter at a time. The holding device is supported by mechanism that can offer a selective portion of the work piece to milling cutter for its processing. Indexing is one of the examples of this type of processing.



**Figure 1.1 Cutting principle [19]**

## 1.4 TYPES OF MILLING OPERATIONS

Milling operation is broadly classified as peripheral milling and face milling as follows:

### 1.4.1 Peripheral Milling

This operation is also called plain milling operation. In this operation axis of rotating tool is always kept parallel to the surface being machined. This operation is done by the cutting edges on outside periphery of the milling cutter. Different type of peripheral milling operations are possible as described below.

#### Slab Milling

In this milling operation the cutter width extends beyond the work piece on both sides.

#### Slotting

It is also a type of milling operation, also called as slot milling operation. In this case width of the cutter is less than the width of work piece. It is used to make slot in the work piece. Thin slots can be made by using very thin milling cutters. The work piece can be cut into two pieces by making a very thin slot throughout the depth of work piece. Cutting the work piece this way by slot milling is called saw milling.

#### Side Milling

The cutter is used for milling of sides of a work piece.

#### Straddle Milling

It is just like side milling with difference that cutting (milling operation) takes place simultaneously on both the sides of work piece.

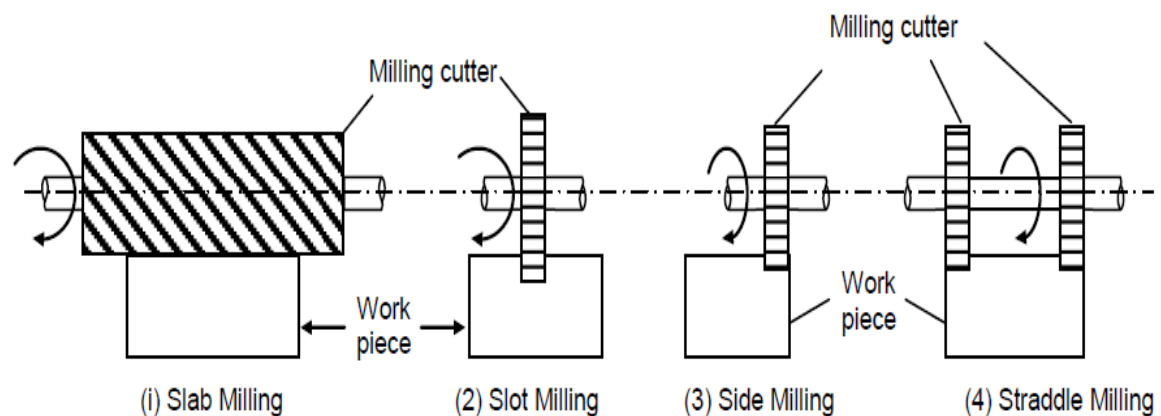


Figure 1.2 Types of peripheral milling [20]

### **1.4.2 Face milling**

In the operation of face milling, axis of the milling cutter remains perpendicular to the surface being milled. In this case cutting action is done by cutting edges of both sides (end and out side) periphery of the milling cutter. Depending upon the relative geometry of work piece and milling cutter face milling is different types as described below.

#### **Conventional Face Milling**

In this case diameter of milling cutter is greater than the width of work piece. The milling cutter remains over hanging on both sides of work piece.

#### **Partial Face Milling**

In this case the milling cutter overhangs on the work piece on one side only.

#### **End Milling**

In case of end milling thin (low diameter) cutter are used as compared to work piece width. It is used to make slot in the work piece.

#### **Profile Milling**

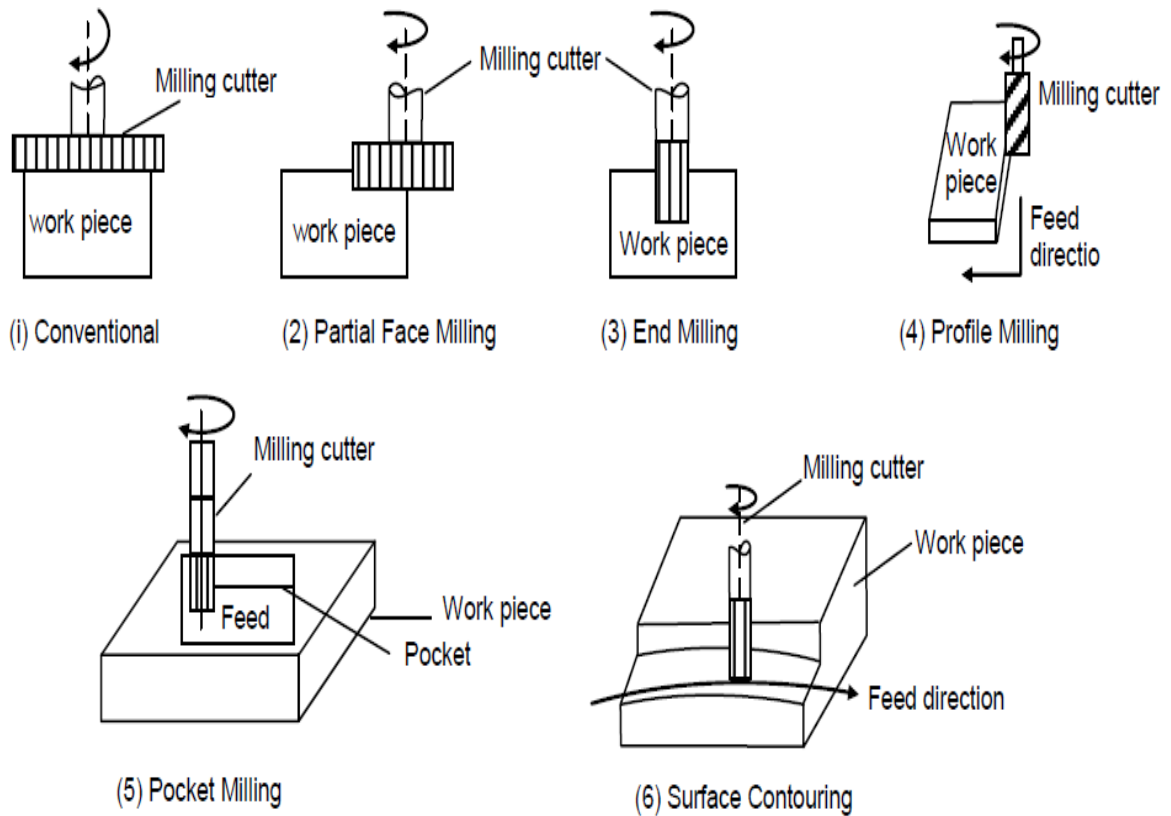
This is just like end milling in which the outer side periphery of a flat part is machined (milled).

#### **Pocket Milling**

This is a selective portion milling on the flat surface of work piece used to make shallow packets there.

#### **Surface Contouring**

In this operation a ball nose cutter if feedback and forth across the work piece along a curvilinear path at short intervals. This creates the required contours on the surface of work piece. This operation is used to make contours of moulds and dies and this time the operation is named as die sinking.



**Figure 1.3 Types of face milling [20]**

## 1.5 TYPES OF MILLING MACHINE

Milling machines can be classified into different categories depending upon their construction, specification and operations. The broader classification has three categories and each category has its sub-classifications given below

### 1.5.1 Column and Knee Type Milling Machine

- Head milling machine
- Plain milling machine
- Universal milling machine
- Omniversal milling machine
- Vertical milling machine

### **1.5.2 Fixed Bed Type Milling Machine**

- Simplex milling
- Duplex milling
- Triplex milling

### **1.5.3 Special Type Milling Machine**

- Rotary table milling
- Drum milling
- Planetary milling
- Tracer controlled milling

### **1.5.1 Column and Knee Type Milling Machine**

Main shape of column knee type of milling machine is shown in Figure 1.3. This milling machine consists of a base having different control mechanisms housed there in. The base consists of a vertical column at one of its end. There is one more base above the main base and attached to the column that serves as worktable equipped with different attachments to hold the work piece. This base having worktable is identified as “knee” of the milling machine. At the top of the column and knee type milling machines are classified according to the various methods of supplying power to the table, different movements of the table and different axis of rotation of the main spindle. These are described in brief as below.

#### **Head Milling Machine**

In case of head milling machine feed motion is given by hand and movements of the machine are provided by motor. This is simple and light duty milling machine meant for basic operations.

#### **Plain Milling Machine**

Plain milling machine is similar to hand milling machine but feed movement can be powered controlled in addition to manual control.

#### **Universal Milling Machine**

A universal milling machine is named so as it is used to do a large variety of operations. The distinguishing feature of this milling machine is its table which is mounted on a circular swiveling base which has degree graduations. The table can be

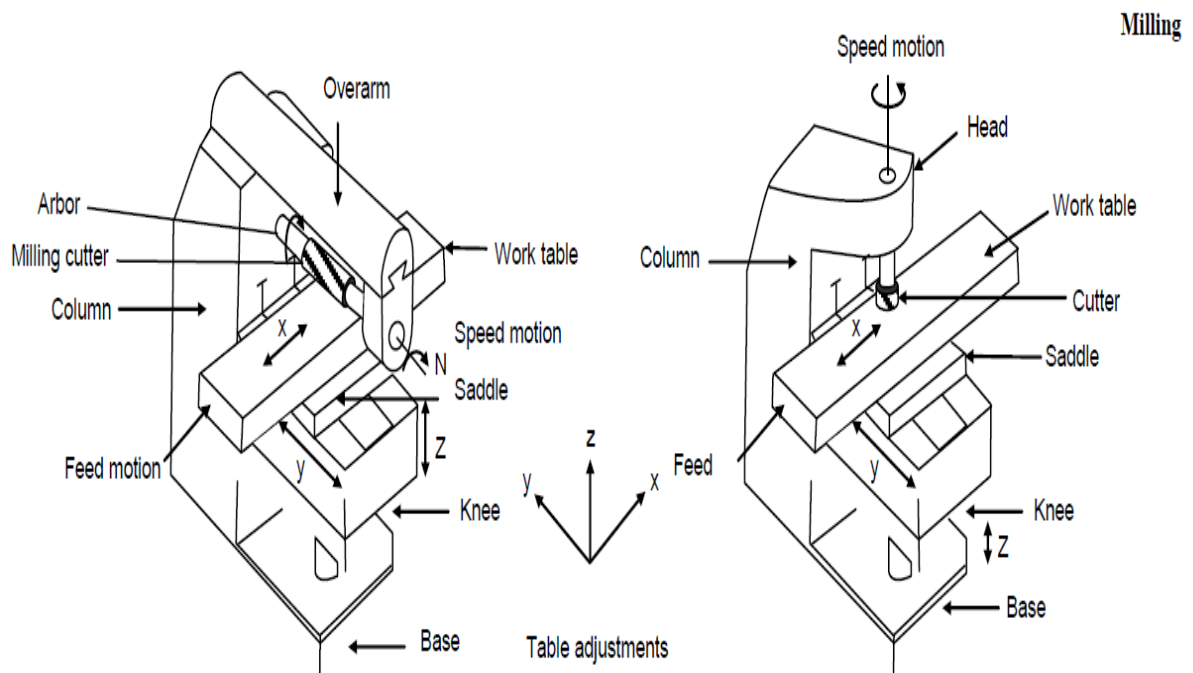
swiveled to any angle upto  $45^\circ$  on either side of normal position. Helical milling operation is possible on universal milling machine as its table can be fed to cutter at an angle. Provision of large number of auxiliaries like dividing head, vertical milling attachments, rotary table, etc. make it suitable for wide variety of operations.

### **Omniversal Milling Machine**

Omniversal milling machine is like a universal milling machine with additional feature that its table can be tilted in a vertical plane by providing a swivel arrangement at the knee. This enables it to make taper spiral grooves in reamers, bevel gears, etc.

### **Vertical Milling Machine**

Position of spindle is kept vertical or perpendicular to the worktable in case of vertical milling machine.



**Figure 1.4 Coloumn and knee type milling machine [21]**

### 1.5.2 Fixed Bed Type Milling Machine

It is also known as manufacturing type milling machine. Its table is mounted directly on the ways of fixed bed. Table movement is restricted to reciprocation only. Cutter is mounted on the spindle head which can move vertically on the column. Duplex milling machine has double spindle heads, one on each side of the table. Triplex milling machine has three spindle heads one each side of the table and third one is mounted on the cross rail.

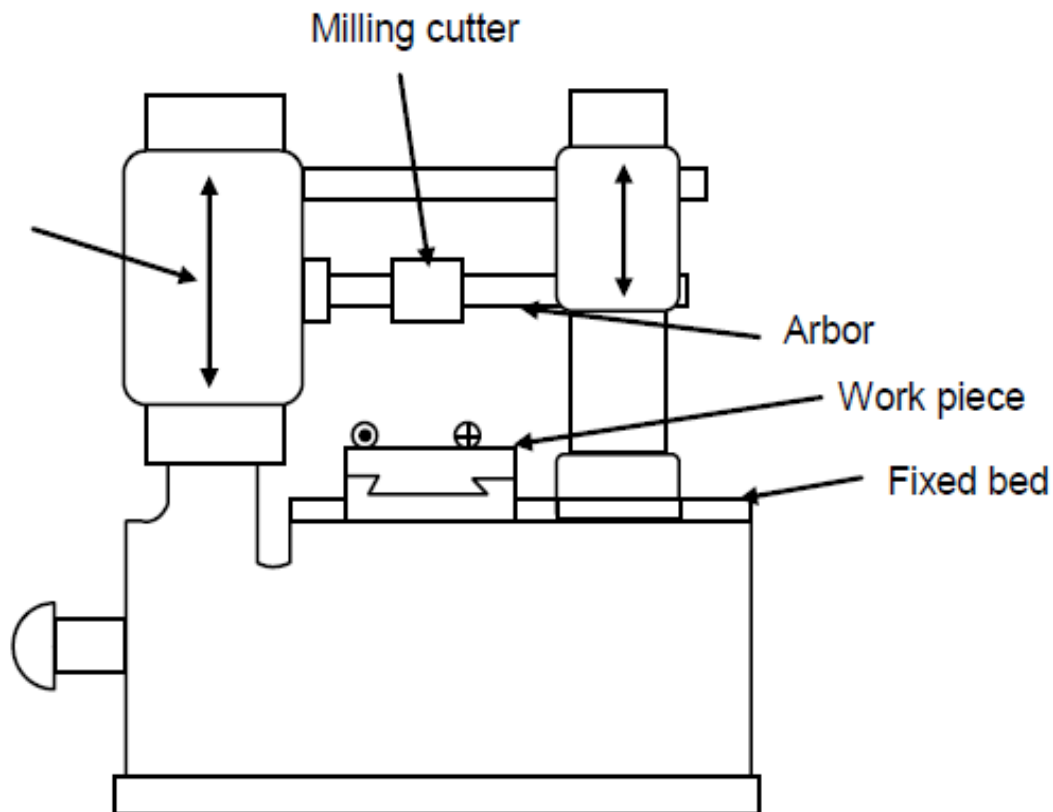


Figure 1.5 Fixed bed type milling machine [21]

### 1.5.3 Special Type Milling Machines

These are the special purpose milling machines, entirely different in design and construction from the conventional milling machines. In case of rotary table milling machine face milling cutters are mounted on two or more vertical spindles and a number of workpieces are clamped on the horizontal surface of a circular table which rotates about a vertical axis. Different milling cutters are mounted at different heights. Loading and unloading are possible while milling is in progress. In case of drum

milling machine the worktable rotates about a horizontal axis and is called drum. In a planetary milling machine, the work is held stationary while the revolving cutters in a planetary path. It is used to finish cylindrical surface of a work piece internally or externally or both. Pantograph milling machine reproduced the work piece at any desired scale of pre-decided model. Profiling machine duplicates full size of the template attached to the machine. Tracer milling machine can produce any pre-decided irregular or complex shapes of dies, moulds by synchronizing movements of the cutter and tracing elements.

## 1.6 CONSTRUCTION OF MILLING MACHINE

Here we discuss the construction of horizontal milling machine. Main components of machine are base, column, knee, saddle, table, over arm, arbor support and elevating screw.

- **Base** It gives support and rigidity to the machine and also acts as a reservoir for the cutting fluids.
- **Column** The column is the main supporting frame mounted vertically on the base. The column is box shaped, heavily ribbed inside and houses all the driving mechanisms for the spindle and table feed.
- **Knee** The knee is a rigid casting mounted on the front face of the column. The knee moves vertically along the guide ways and this movement enables to adjust the distance between the cutter and the job mounted on the table. The adjustment is obtained manually or automatically by operating the elevating screw provided below the knee.
- **Saddle** The saddle rests on the knee and constitutes the intermediate part between the knee and the table. The saddle moves transversely, i.e., crosswise (in or out) on guide ways provided on the knee.
- **Table** The table rests on guide ways in the saddle and provides support to the work. The table is made of cast iron, its top surface is accurately machined and carries T-slots which accommodate the clamping bolt for fixing the work. The worktable and hence the job fitted on it is given motions in three directions:

- a) Vertical (up and down) movement provided by raising or lowering the knee.
- b) Cross (in or out) or transverse motion provided by moving the saddle in relation to knee.
- c) Longitudinal (back and forth) motion provided by hand wheel fitted on the side of feed screw.

In addition to the above motions, the table of a universal milling machine can be swiveled  $45^\circ$  to either side of the centre line and thus fed at an angle to the spindle.

- **Overarm** The Overarm is mounted at the top of the column and is guided in perfect alignment by the machined surfaces. The Overarm is the support for the arbor.
- **Arbor support** The arbor support is fitted to the Overarm and can be clamped at any location on the Overarm. Its function is to align and support various arbors. The arbor is a machined shaft that holds and drives the cutters.
- **Elevating screw** The upward and downward movement to the knee and the table is given by the elevating screw that is operated by hand or an automatic feed.

## 1.7 MILLING PROCESS PARAMETERS

### 1.7.1 Milling cutting geometry

#### 1) True rake

True rake is the slope of the tooth face with respect to radial reference plane through the nose of the cutting edge and is the resultant of the radial, axial and angles. It is measured in the perpendicular to the surface generated by the cutting edge. The true rake of a given radial and axial combination becomes more positive as the lead angle increases, which offers free cutting and lower horsepower consumption.

#### 2) Angle of inclination

The same angles used to determine true rake are also used to measure inclination angles. The plane of measurement differs, however measurement is made from the plane generated by the cutting edge rather than perpendicular to it.

### 3) Cutting effect on surface finish

A number of variable affects the surface finish produced by a cutter, such as machine rigidity, work material, fixturing and feed rate. Once method of improving the surface finish is by using an insert that has a wiper flat, to be effective , the wiper flat should be approximately 25% longer than the feed per revolution in order to wipe out any high points left by the preceding inserts.

## 1.8 CUTTING PARAMETERS

There are three major cutting parameters to be controlled in any milling operation. These three parameters are cutting speed, feed rate and depth of cut. These parameters are described below.

### 1.8.1 Cutting Speed

Cutting speed of a milling cutter is its peripheral linear speed resulting from operation. It is expressed in meters per minute. The cutting speed can be derived from the formula.

$$V = \frac{\pi d n}{1000} \dots\dots\dots(1.1)$$

where  $d$  = Diameter of milling cutter in mm,

$V$  = Cutting speed (linear) in meter per minute, and

$n$  = Cutter speed in revolution per minute.

Spindle speed of a milling machine is selected to give the desired peripheral speed of cutter.

### 1.8.2 Feed Rate

It is the rate with which the work piece under process advances under the revolving milling cutter. It is known that revolving cutter remains stationary and feed is given to the work piece through worktable. Generally feed is expressed in three ways.

### 1.8.3 Feed per Tooth

It is the distance traveled by the work piece (its advance) between engagement by the two successive teeth. It is expressed as mm/tooth ( $ft$ ).

### 1.8.4 Feed per Revolution

Travel of work piece during one revolution of milling cutter. It is expressed as mm/rev. and denoted by  $f$  (rev).

### 1.8.5 Feed per Unit of Time

Feed can also be expressed as feed/minute or feed/sec. It is the distance advances by the work piece in unit time (fm).

Above described three feed rates are mutually convertible.

$$f_m = n \times f_{rev} \dots\dots\dots(1.2)$$

where  $n$  = rpm of cutter.

It can be extended further as

$$f_m = n \times f_{rev} = z \times n \times f_t \dots\dots\dots(1.3)$$

where  $z$  = Number of teeth in milling cutter.

### 1.8.6 Depth of Cut

Depth of cut in milling operation is the measure of penetration of cutter into the work piece. It is thickness of the material removed in one pairs of cutter under process. One pairs of cutter means when cutter completes the milling operation from one end of the work piece to another end. In other words, it is the perpendicular distance measured between the original and final surface of work piece. It is measured in mm.

## **2.1 INTRODUCTION**

A large work has been done on different aspects of milling machine. This chapter covers the literature of on various input parameters of milling machine and its effect on MRR , surface roughness and hardness on different materials.

## **2.2 LITERATURE SURVEY**

A considerable amount of research has been conducted on the effects of milling on various materials. Most has been targeted toward the study of surface roughness.

### **2.2.1 ACCORDING TO MACHINING ON ALLOYS**

**Kopac and Krajnik [1] (2007)** studied the cutting loads, milled surface roughness and the material removal rate (MRR) in the machining of an Al-alloy casting plate for injection moulds. The considered flank milling parameters include the coolant employment, number of end mill flutes, cutting speed, feed per tooth, axial depth of cut, and radial depth of cut. Grey-Taguchi method is combining the orthogonal array (OA) design of experiments (DOE) with grey-relational analysis (GRA), which enables the determination of the optimal combination of flank milling parameters for multiple process responses. The basic idea of GRA is to find a grey-relational grade (GRG), which can be used for the optimization conversion from a multi-objective case to a single-objective case. GRG is also used to estimate the parameter effects on the overall performance response.

**Zain, Haron and Sharif [2] (2010)** studied the effect of the radial rake angle of the tool, combined with speed and feed rate cutting conditions in influencing the surface roughness result. In machining, the surface roughness value is targeted as low as possible and is given by the value of the optimal cutting conditions. By looking at previous studies, as far as they have been reviewed, it seems that the application of GA optimization techniques for optimizing the cutting conditions value of the radial rake angle for minimizing surface roughness in the end milling of titanium alloy is

still not given consideration by researchers. Therefore, having dealt with radial rake angle machining parameter, this study attempts the application of GA to find the optimal solution of the cutting conditions for giving the minimum value of surface roughness. By referring to the real machining case study, the regression model is developed. The best regression model is determined to formulate the fitness function of the GA. The analysis of this study has proven that the GA technique is capable of estimating the optimal cutting conditions that yield the minimum surface roughness value. With the highest speed, lowest feed rate and highest radial rake angle of the cutting conditions scale, the GA technique recommends 0.138 lm as the best minimum predicted surface roughness value. This means the GA technique has decreased the minimum surface roughness value of the experimental sample data, regression modelling and response surface methodology technique by about 27%, 26% and 50%, respectively.

**Kadirgama, Noor and Alla [3] (2010)** optimized surface roughness by using milling mould aluminium alloys (AA6061-T6) with Response Ant Colony Optimization (RACO). The approach is based on Response Surface Method (RSM) and Ant Colony Optimization (ACO). The main objectives to find the optimized parameters and the most dominant variables (cutting speed, feedrate, axial depth and radial depth). The first order model indicates that the feedrate is the most significant factor affecting surface roughness. Metal cutting processes are important due to increased consumer demands for quality metal cutting related products (more precise tolerances and better product surface roughness) that has driven the metal cutting industry to continuously improve quality control of metal cutting processes.

**Routara, Mohanty, Datta, Bandyopadhyay and Mahapatra [4] (2010)** studied 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. The study aimed at evaluating the best process environment which could simultaneously satisfy multiple requirements of surface quality. The traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation, utility theory has been coupled with Taguchi method. Depending on Taguchi's Lower-the-Better (LB) response criteria; individual surface quality characteristics has been transformed into corresponding utility values. Individual

utility values have been aggregated finally to compute overall utility degree which serves as representative objective function for optimizing using Taguchi method. 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. The study of combined utility theory and Taguchi method for predicting optimal setting. Based on Taguchi's Signal-to- Noise ratio (S/N), analysis has been made on the overall utility degree and optimal process environment has been selected finally which corresponds to highest S/N Ratio. Optimal result has been verified through confirmatory test. The case study indicates application feasibility of the aforesaid methodology proposed for multi response optimization and off-line control of multiple surface quality characteristics in CNC end milling.

**Kadirgam Et. al. [5] (2008)** investigated the surface roughness when milling Mould Aluminium alloys (AA6061-T6) with carbide coated inserts. Optimization of milling is very useful to reduce cost and time for machining mould. The approach is based on Response Surface Method (RSM) and Radian Basis Function Network (RBFN). RBFN was successfully used by Tsoa and Hocheng in their recent research. They used this network to predict thrust force and surface roughness in drilling. In this work, the objectives are to find the optimized parameters, and to find out the most dominant variables (cutting speed, federate, axial depth and radial depth). The optimized value has been used to develop a blow mould. The first order model and RBFN indicates that the feed rate is the most significant factors effecting surface roughness. RBFN predict surface roughness more accurately compared to RSM.

**Tsao [6] (2009)** studied the milling parameters of A6061P-T651 aluminum alloy with multiple performance characteristics. A grey relational grade obtained from the grey relational analysis is used as the performance characteristic in the Taguchi method. Then, the optimal milling parameters are determined using the parameter design proposed by the Taguchi method. Experimental results indicate that the optimal process parameters in milling A6061P-T651 aluminum alloy can be determined effectively; the flank wear is decreased from 0.177 mm to 0.067 mm and the surface roughness is decreased from 0.44  $\mu\text{m}$  to 0.24  $\mu\text{m}$ , leading to a multiple performance characteristics improvement in milling qualities through the grey-Taguchi method.

### 2.2.2 ACCORDING TO MACHINING ON COMPOSITES

**Davim and Reis [7] (2005)** studied that evaluates the cutting parameters (cutting velocity and feed rate) under the surface roughness, and damage in milling laminate plates of carbon fiber-reinforced plastics (CFRPs). A plan of experiments, based on the Taguchi's method, was established considering milling with prefixed cutting parameters in an autoclave CFRP composite material. An analysis of variance (ANOVA) was performed to investigate the cutting characteristics of CFRP composite material using cemented carbide (K10) end mills. The objective was to establish a model using multiple regression analysis between cutting velocity and feed rate with the surface roughness and damage in a CFRP composite material. Milling composite materials is a rather complex task owing to its heterogeneity and the number of problems, such as surface delamination, that appear during the machining process, associated with the characteristics of the material and the cutting parameters. With the purpose of understanding and reducing these problems.

**Davim, Reis and Antonio [8] (2004)** studied with the objective of evaluating the cutting parameters (cutting velocity and feed rate) related to machining force in the work piece, delamination factor, surface roughness and international dimensional precision in two GFRP composite materials (Viapal VUP 9731 and ATLAC 382-05). A plan of experiments, based on an orthogonal array, was established considering milling with prefixed cutting parameters. Finally an analysis of variance (ANOVA) was performed to investigate the cutting characteristics of GFRP composite materials using a cemented carbide (K10) end mill. Milling is the most practical machining (corrective) operation for removing excess material to produce a well defined and high quality surface. However, milling composite materials presents a number of problems such as surface delamination associated with the characteristics of the material and the cutting parameters used.

**Raj and Perumal [9] (2010)** studied surface roughness, precision and delamination factor in use of Ti-Namite carbide K10 end mill, Solid carbide K10 end mill and Tipped Carbide K10 end mill. A plan of experiment based on Taguchi was established with prefixed cutting parameters and the machining was performed. An Surfcooder to examine the surface roughness and Infrared Thermography to examine the

delamination of chopped Glass fiber-reinforced plastic (GFRP) laminates was used. Earlier works reports that cutting velocity and feed rate makes significant contribution to overall performance. But, the experimental results of this paper indicates that the depth of cut are recognised to make the most significant contribution to the overall performance as compared to cutting velocity and feed rate. The objective was to establish a correlation between cutting velocity, feed rate and depth of cut with surface roughness and delamination in a GFRP laminate. The correlation was obtained by multiple-variable linear regression using Minitab14 software.

**Shetty, Pai, Kamath and Rao [10] (2008)** used of Taguchi and response surface methodologies for minimizing the surface roughness in turning of discontinuously reinforced aluminum composites (DRACs) having aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles of mean diameter 25 $\mu$ m under pressured steam jet approach. The measured results were then collected and analyzed with the help of the commercial software package MINITAB15. The experiments have been conducted using Taguchi's experimental design technique. The matrix of test conditions included cutting speeds of 45, 73 and 101 m/min, feed rates of 0.11, 0.18 and 0.25 mm/rev and steam pressure 4, 7, 10 bar while the depth of cut has been kept constant at 0.5 mm. The effect of cutting parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined. A second-order model has been established between the cutting parameters and surface roughness using response surface methodology. The experimental results reveal that the most significant machining parameter for surface roughness is steam pressure followed by feed. The predicted values and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness in the machining of DRACs.

**Dabade, Joshi and Ramakrishnan [11]** studied the cutting process performed using a specially designed and fabricated self propelled rotary inserts facing milling cutter. Statically designed experiments were performed using Taguchi method with surface roughness and chip crosssectional area as response variables. Analysis of experimental results using analysis of variance is discussed in details. It is observed that inclination angle is the most significant factor influencing both surface roughness and chip crosssectional area and can give better results in range of 30-45.

### 2.2.3 ACCORDING TO MACHINING ON STEELS

**Ghani, Choudhury and Hassan [12] (2004)** optimized cutting parameters in end milling when machining hardened steel AISI H13 with TiN coated P10 carbide insert tool under semi-finishing and finishing conditions of high speed cutting. The milling parameters evaluated are cutting speed, feed rate and depth of cut. An orthogonal array, signal-to-noise (S/N) ratio and Pareto analysis of variance (ANOVA) are employed to analyze the effect of these milling parameters. The analysis of the result shows that the optimal combination for low resultant cutting force and good surface finish are high cutting speed, low feed rate and low depth of cut. Using Taguchi method for design of experiment (DOE), other significant effects such as the interaction among milling parameters are also investigated. The study shows that the Taguchi method is suitable to solve the stated problem with minimum number of trials as compared with a full factorial design.

**Gologlu and Sakarya [13] (2008)** investigated optimum cutting characteristics of DIN 1.2738 mould steel using high-speed steel end mills. The cutting parameters considered are cutting velocity, feed rate, depth of cut and step over. The second aim is to identify the effects of cutter path strategies when employing in pocket milling. The both aims will be addressed by means of using Taguchi parameter design. In pocket milling which is often encountered in plastic mould manufacture, the demand is to narrow the interval between the surface roughness values obtained at finish milling and the surface roughness values will be met by further finishing operations as far as possible. The implementation and selection of cutting path strategies with appropriate cutting parameters have significant effect on surface roughness. The effect of every single variable on surface roughness is known, however, what kind of results is revealed in their combinations cannot be clearly estimated.

**Hou, Su and Liu [14] (2007)** studied the parameter design of the Taguchi method, response surface method (RSM) and genetic algorithm (GA) are integrated and applied to set the optimal parameters for a nano-particlemilling process. The orthogonal array experiment is conducted to economically obtain the response measurements. Analysis of variance (ANOVA) and main effect plot are used to determine the significant parameters and set the optimal level for each parameter. The

RSM is then used to build the relationship between the input parameters and output responses, and used as the fitness function to measure the fitness value of the GA approach. Finally, GA is applied to find the optimal parameters for a nano-particle milling process. The experimental results show that the integrated approach does indeed find the optimal parameters that result in very good output responses in the nano-particle wetmilling process. Nano-particles have been successfully and widely applied in many industrial applications. The wet-type mechanical milling process is a popular method used to produce nano-particles. Therefore, it is very important to improve milling process capability and quality by setting the optimal milling parameters.

**Savas and Ozay [15] (2007)** studied performance assessment of rotary end milling at the tangential contact. With this shape of the contact, process has been more stable. At the last decade due to the fact that cutting tools have a quenching problem, Turn-milling has been developing in manufacturing technology for processing hard steels, where in both the work piece and the tool are given a rotary movement simultaneously. Thus, cutting edges have a time for quenching. The objective of present work is to investigate process of tangential turn-milling for machining of work pieces with in the normally available range of speed and feeds to explore its advantages. The investigations have been laid mainly on surface roughness and timing process. The experiments have been conducted for tangential turn-milling of mild steel work piece.

**Kuram, Simsek, Ozcelik, Demirbas and Askin [16] (2010)** studied two different vegetable based cutting fluids developed from refined canola and sunflower oil and a commercial type semi-synthetic cutting fluid were carried out to determine optimum conditions for tool wear and forces during milling of AISI 304 austenitic stainless steel. Taguchi L9 (34) orthogonal array was used for the experiment plan. Cutting speed, feed rate, depth of cut and types of cutting fluids were considered as machining parameters. Mathematical models for cutting parameters and cutting fluids were obtained from regression analyses to predict values of tool wear and forces. S/N ratio and ANOVA analyses were also performed to obtain for significant parameters influencing tool wear and forces.

**Zhang, Chen and Kirby [17] (2007)** studied the Taguchi design application to optimize surface quality in a CNC face milling operation. Maintaining good surface quality usually involves additional manufacturing cost or loss of productivity. This study included feed rate, spindle speed and depth of cut as control factors, and the noise factors were the operating chamber temperature and the usage of different tool inserts in the same specification, which introduced tool condition and dimensional variability. An orthogonal array of L9 was used. ANOVA analyses were carried out to identify the significant factors affecting surface roughness, and the optimal cutting combination was determined by seeking the best surface roughness (response) and signal-to-noise ratio. Finally, confirmation tests verified that the Taguchi design was successful in optimizing milling parameters for surface roughness.

**Moshat, Datta, Bandyopadhyay and Pal [18] (2010)** studied CNC end milling process parameters to provide good surface finish as well as high material removal rate (MRR). The surface finish and material removal rate have been identified as quality attributes and are assumed to be directly related to productivity. An attempt has been made to optimize aforesaid quality attributes in a manner that these multi-criteria could be fulfilled simultaneously up to the expected level. This invites a multi-objective optimization problem which has been solved by PCA based Taguchi method. To meet the basic assumption of Taguchi method, in the present work, individual response correlations have been eliminated first by means of Principal Component Analysis (PCA). Correlated responses have been transformed into uncorrelated or independent quality indices called principal components. The principal component, imposing highest accountability proportion, has been treated as single objective function for optimization (multi-response performance index). Finally Taguchi method has been adapted to solve this optimization problem. The aforesaid methodology has been found fruitful in the cases where simultaneous optimization of huge number of responses is required.

### **3.1 OBJECTIVE OF THE PRESENT WORK**

The objective of the present work is to find out main effect of pressure of steam, cutting speed, feed rate, depth of cut and interaction effect between steam pressure and cutting speed on MRR, surface roughness and hardness of work piece. The formula used for measuring the MRR are given below:

MRR is given by:

$$\text{MRR} = \frac{W_i - W_f}{\rho t} \times 1000 \text{ mm}^3/\text{min} \quad \dots\dots\dots(3.1)$$

$W_i$  =Initial weight of work piece material in grams

$W_f$  =Final weight of work piece material in grams

$t$  =Time period of machining in minutes

$\rho$  = Density of work piece in gms/cm<sup>3</sup>

### **3.2 DEGREE OF FREEDOM (DOF)**

Total degree of freedom required for the entire experimentation is determined by the number of factors, their interactions effects and level for factors. The degree of freedom for each factor is given by the number of levels minus one.

DOF for each factor = k-1

Where k is the number of level for each factor

DOF for interactions between factors : (kA-1) × (kB-1)

Where kA and kB are number of level for factor A and B

### **3.3 SELECTION OF FACTORS**

The determination of factors which needs to be investigated depends on the responses of interest. The factors that affect the responses were identified using several methods such as brainstorming, cause and effect analysis and flowcharting. The lists of factors studied with their levels are given in the Table 3.1. The minimum dof required in the experiment are the sum of all the degrees of freedom of factors and their interaction. In the present experiment setup, there are 3 three level factors and one is 2-level factor

i.e steam pressure. The number of dof for factors B, C, D are two and for factor A is one. The total dof for the experiment is explained in Table 3.2. As the dof required for the experiment is 9 the orthogonal array (OA) to be used should have more than 9 dof. The most suitable orthogonal array which can be used for this experiment is L18, which has 17 DOF assigned to its various columns. The additional eight dof were used to measure the random error.

**Table 3.1: Factors and their levels of interest**

Factors	Factors designation	Level 1	Level 2	Level 3
Steam jet pressure (lb/in <sup>2</sup> )	A	15	25	
Speed (rpm)	B	450	900	2900
Feed rate (mm/min)	C	20	35	65
Depth of cut (mm)	D	0.5	0.75	1

**Table 3.2 Degree of freedom**

Factors	A	B	C	D	A*B	Total
Degree of freedom	1	2	2	2	2	9

### 3.4 ORTHOGONAL ARRAY

OA derived from factorial design of experiment by a series of very sophisticated mathematical algorithms including combinatory, finite fields, geometry and error correcting codes. OA plays a critical part in achieving the high efficiency of the Taguchi method. The OA is constructed in a statistically independent manner. Within each column, number of occurrences of each level is equal and for each level within

one column, each level within any other column will occur an equal number of times as well. Then, the columns are called orthogonal to each other. OA is available with a variety of factors and levels in the Taguchi method. Since each column is orthogonal to the others, if the results associated with one level of a specific factor are much different at another level, it is because changing that factor from one level to the next has strong impact on the quality characteristic being measured. Since the levels of the other factors are occurring an equal number of times for each level of the strong factor, any effect by these other factors will be ruled out. The selection of orthogonal array will depend on:

- The number of factors and interactions of interest
- The number of levels for the factors of interest

Taguchi orthogonal arrays are experimental designs that usually require only a fraction of the full factorial combinations. The columns of arrays are balanced and orthogonal. This means that in each pair of columns, all factor combinations occur same number of times. Orthogonal designs allow estimating the effect of each factor on the response independently of all other factors. Once the degrees of freedom are known, the next step is to select the orthogonal array (OA). The number of treatment conditions is equal to the number of rows in the orthogonal array and it must be equal to or greater than the total degrees of freedom. Once the appropriate orthogonal array has been selected, the factor can be assigned to the various columns [49]. L18 Linear graph is shown in figure 3.1 that's used in experiment and experimental design of L18 is shown in Table 3.3.



**Figure 3.1: L18 Linear Graph**

The 18 experimental designs represent the set of values of input process parameters with which particular experiment is to be conducted. Machining time during each experiment 31 was 3 minutes. The total 18 experiment were performed with repetition in order to minimize the effect of uncontrollable factors for each combination of all input parameters.

**Table 3.3: L18 Experimental design**

Experiment no:	Pressure (lb/in <sup>2</sup> )	Speed (rpm)	Feed (mm/min)	DOC (mm)
1	15	450	20	0.50
2	15	450	35	0.75
3	15	450	65	1
4	15	900	20	0.50
5	15	900	35	0.75
6	15	900	65	1
7	15	2900	20	0.75
8	15	2900	35	1
9	15	2900	65	0.50
10	25	450	20	1
11	25	450	35	0.50
12	25	450	65	0.75
13	25	900	20	0.75
14	25	900	35	1
15	25	900	65	0.50
16	25	2900	20	1
17	25	2900	35	0.50
18	25	2900	65	0.75

### 3.5 EXPERIMENTAL SET UP

The experiments have been conducted on Vertical milling machine shown in (Figure 3.2) available at Thapar University, Patiala in the Machine Tool lab. Many input parameters like steam pressure, cutting speed, feed and depth of cut has been varied in this experiment. Each factors has its own effect on the output parameters such as Material removal rate (MRR), Surface roughness (SR), and hardness. In all experiments machining time is kept constant of 3 minutes.

For attaining steam jet approach vertical milling machine was equipped with a steam generating cooker (figure 3.3). This was capable of producing pressure upto 30 lb/in<sup>2</sup>

(figure 3.3). In experiments only two values of pressure were considered as 15 and 25 . The outlet of pressure was with the help of a pipe and nozzle that was located near to the groove made by machining, for the fast removal of material removed. . Steam jet act as transportation carriers carrying the heat away from the cutting region, and the efficiency of this cooling method largely depends on the jet pressure.



**Figure 3.2: Vertical milling machine [Non traditional machining lab]**



**Figure 3.3: Steam generator with pressure gauge**  
**[Non traditional machining lab]**

### 3.6 SPECIFICATIONS OF VERTICAL MILLING MACHINE

- |                                 |   |
|---------------------------------|---|
| 1. Machine Number               | 883/2/90  |
| 2. Machine type                 | VM-25-A   |
| 3. Manufacturers                | New Bharat Engineering Works Pvt Ltd (Jamnagar) |
| 4. Motor number                 | 807 (3-phase)                                   |
| 5. Horse power of driving motor | 0.75/1 HP                                       |
| 6. Voltage                      | 415 volt  |
| 7. Current                      | 1.3/1.9 amp                                     |
| 8. Cycles                       | 50  |
| 9. RPM                          |   |

A	102	204	340	450
B	680	900	1450	2900

10. Depth of cuts (mm) 0, 0.25, 0.5, 0.75, 1, 1.25

11. Feed (mm/min)

A	20	35	65
B	100	175	315

### 3.7 MEASURING AND TEST EQUIPMENT USED

Basically surface roughness, MRR and surface hardness were measured. Surface roughness tests were conducted on all the 18 samples produced by the radial drilling machine. MRR was measured using an electric balance (Sartorius, USA) weighing machine which has a resolution of 0.01 mg, whereas hardness was measured on Rockwell hardness tester. The details of important equipment used for the test in the experimental study are given below.

#### 3.6.1: Surface Roughness Tester

Surface roughness of all the samples are measured by contact type stylus (Mitutoyo SJ-400) Model. The accuracy of this device is To measure the surface roughness, the blocks were Sliced to the holes axes. The surface roughness was measured parallel to each hole axis and the average values of the surface roughness is taken. Surface roughness of a machined product could affect several of the product's functional attributes, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating, and resisting fatigue. There are several ways to describe surface roughness. One of them is average roughness which is often quoted as  $R_a$  symbol.  $R_a$  is defined as the arithmetic value of the departure of the profile from the centerline along sampling length. Profile of Surface roughness is shown in Fig. 3.4.

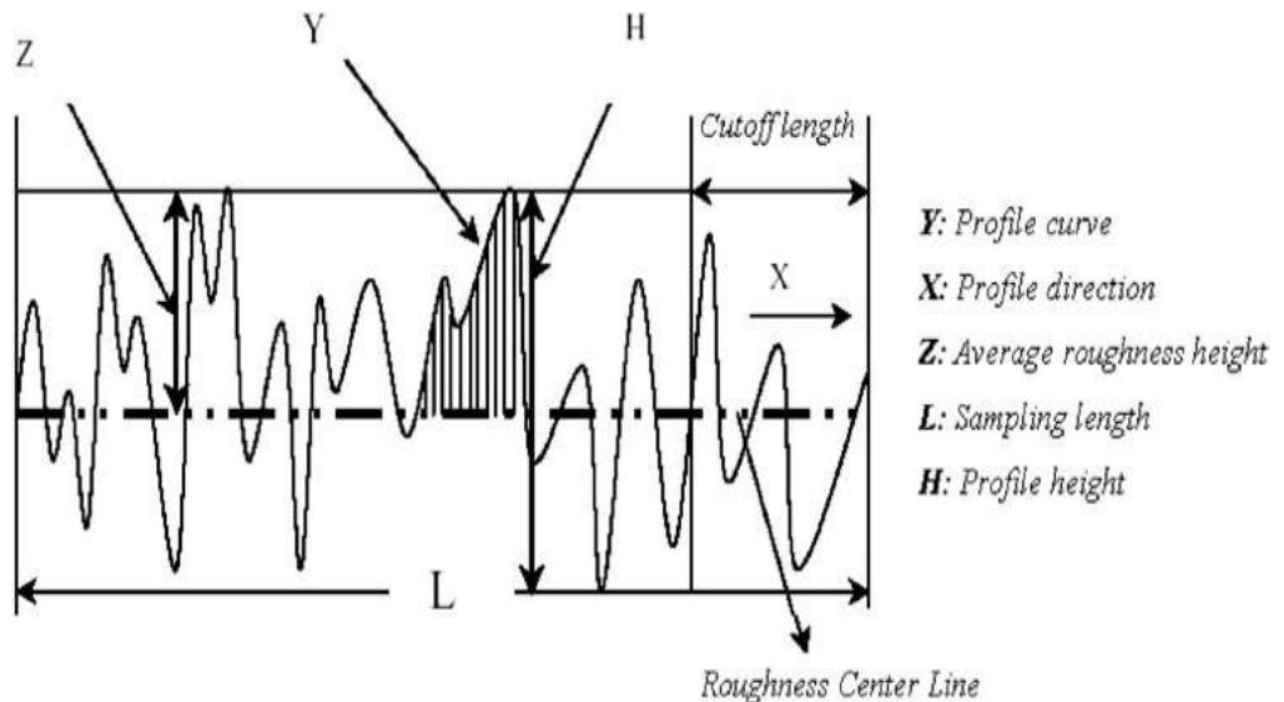


Figure 3.4: Profile of Surface roughness [22]



**Figure: 3.5 Experimental devices for measurement of surface roughness  
[Metrology lab]**

Surface roughness can be expressed by the following mathematical relationships

$$R_a = \frac{1}{L} \int_0^L |Y(x)| dx \quad \dots\dots\dots(3.2)$$

Where Ra arithmetic average deviation from the mean line

Y the ordinate of profile curve

The tools measuring surface roughness with probes, measure, and control in appropriate length and circumference the probe comes in and out holes while travelling on the surface. This movement is turned into electrical current by means of a coil or crystal. After increasing the current by using suitable units, its value is shown with a pointer or digitally.

**3.7.2 Rockwell hardness tester**

The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRB, where B is the scale letter.



**Figure: 3.6 Experimental devices for measurement of surface hardness**

**[Solid mechanics lab]**

### **3.8 TAGUCHI METHODOLOGY**

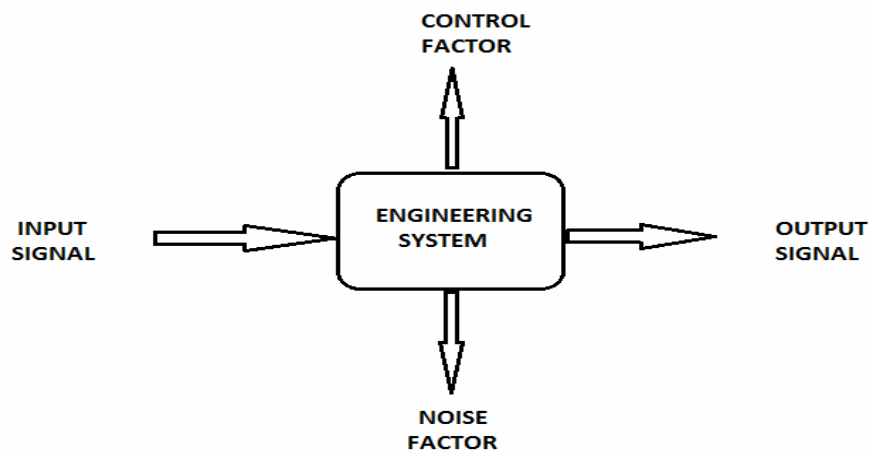
The Taguchi Design is a design of experiment (DOE) approach developed by Dr. Genichi Taguchi in order to improve the quality of manufactured goods in Japan. Although similar to factorial design of experiment, the Taguchi design only conducts balanced (orthogonal) experimental combinations, which makes the Taguchi design even more efficient than a fractional factorial design. The Taguchi methodology has been proposed to overcome the limitations of full factorial analysis by simplifying and standardizing the fractional factorial design (Roy, 1990). Taguchi methodology involves identification of controllable and uncontrollable factors and the establishment of series of experiments to find out optimal combinations of the factors that has the greatest influence on the performance and least variation from the target of the design. The main advantage of Taguchi Design is its efficiency in that multiple factors can be consider at once and the optimal parameters can be identified with fewer experimental resources than the traditional (DOE) approach. In addition,

Taguchi design allows looking into the variation caused by control factors and noise factors, while the variation caused by noise factors is usually ignore in the traditional DOE approach.

Taguchi methods as an engineered system that comprises four main components as illustrated in Fig. 3.7. It is designed to employ energy transformation in converting input signal into specific, intended function requested by customers by applying the laws of physics. Taguchi methods advocate that when all the applied energy is transformed into creating its intended function without any noise effects, a system reach its ideal function.

$$Y = \beta m \dots \dots \dots (3.3)$$

Where a linear relationship exists between Y (= ideal output response) and M (= input signal). However, in reality, energy transformation of any system does not happen as designed or intended due to noise factors disturbing the system.



**Figure 3.7 Experimental designs [23]**

### 3.8.1 Procedure of Taguchi Method

The process has three stages:

1. System design
2. Parameter (measure) design
3. Tolerance design

## **System design**

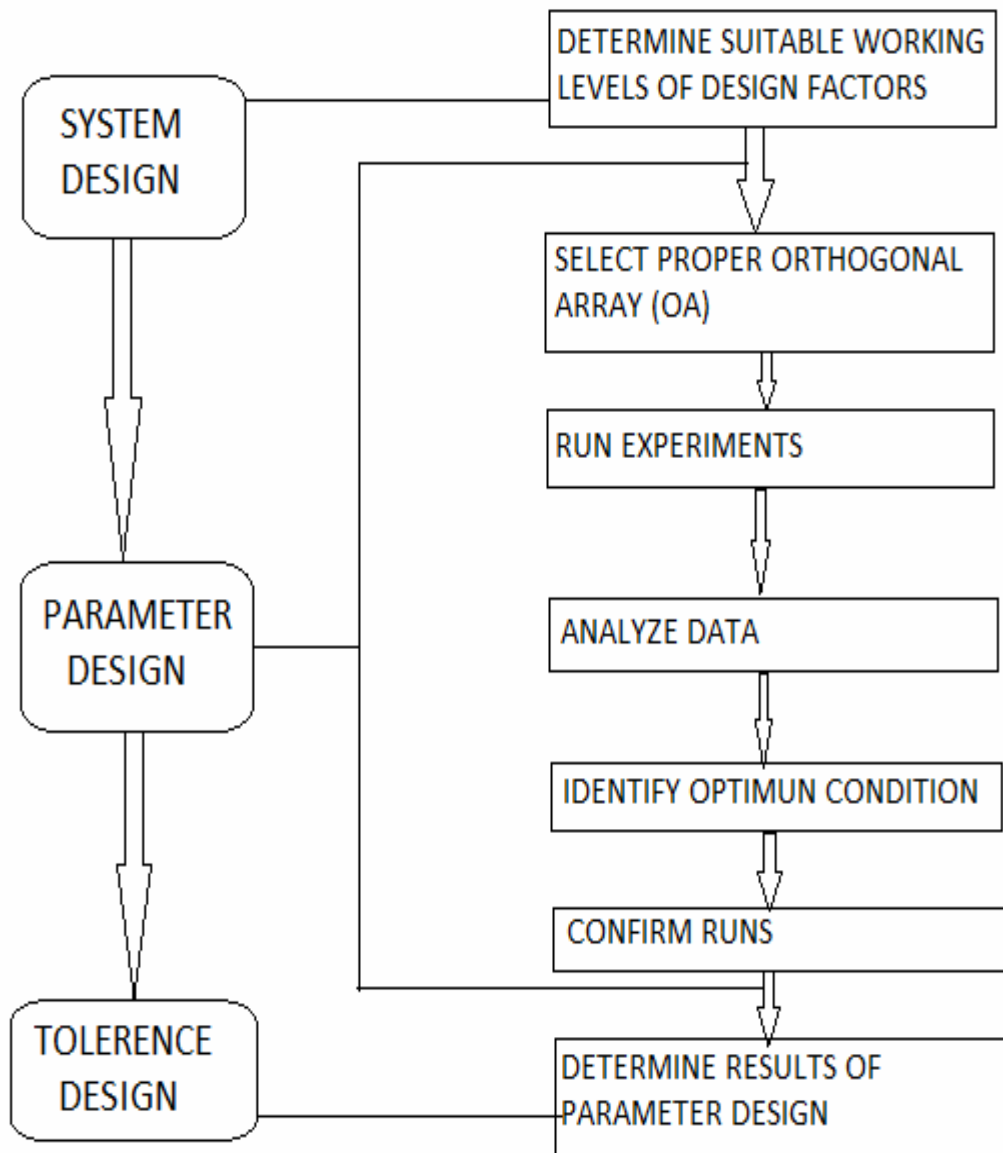
This is design at the conceptual level, involving creativity and innovation.

## **Parameter design**

Once the concept is established, the nominal values of the various dimensions and design parameters need to be set, the detail design phase of conventional engineering. Taguchi's radical insight was that the exact choice of values required is under-specified by the performance requirements of the system. In many circumstances, this allows the parameters to be chosen so as to minimize the effects on performance arising from variation in manufacture, environment and cumulative damage. This is sometimes called robustification.

## **Tolerance design**

With a successfully completed parameter design, and an understanding of the effect that the various parameters have on performance, resources can be focused on reducing and controlling variation in the critical few dimensions.



**Figure 3.8: Taguchi design procedure [1]**

### 3.8.2 Analysis of results

The parameters that influence the output can be categorized into two classes, namely controllable (or design) factors and uncontrollable (or noise) factors. Controllable factors are those factors whose values can be set and easily adjusted by the designer.

Uncontrollable factors are the sources of variation often associated with operational environment. The best settings of control factors as they influence the output parameters are determined through experiments.

**Signal-to-noise ratio:** signal-to-noise (S/N) ratio used in Taguchi methods as an index of robustness because it measures the quality of energy transformation. The S/N ratio used to measure the quality characteristics and the significant process parameters through (ANOVA). The ratio indicates the degree of predictable performance in the presence of noise factors. These S/N ratios can be used to get closer to a given target value (such as tensile strength or baked tile dimensions), or to reduce variation in the product's quality characteristic. For example, one S/N ratio corresponds to what Taguchi called "nominal is best." Such a ratio selected when a specific target value, such as tensile strength, is the design goal. A high value of S/N ratio implies that the signal is much higher than the random affects of the noise factors or higher the quality (Roy, 1990; Taguchi, 1993; Taguchi et al., 2000). From the analysis point of view, there are three possible categories of the response characteristics explained below.

- Smaller the better
- Larger the better
- Nominal the best

**Measurement of F-value of Fisher’s F ratio**

The principle of the *F* test is that the larger the *F* value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. F value is defined as:

$$F = MS \text{ for term} / MS \text{ for error term}$$

Depending on F-value, percentage contribution is calculated of each factor.

**Table 3.4: Response Characteristics**

Response name	Response type	Units
Material Removal Rate (MRR)	Higher the better	mm <sup>3</sup> /min
Surface Roughness	Lower the better	Microns
Surface Hardness	Higher the better	HRB

### 3.8.3 Analysis of variance

The knowledge of the contribution of individual factors is critically important for the control of the final response. The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. This method was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments. ANOVA is a statistically based, objective decision-making tool for detecting any differences in average performance of groups of items tested. It calculates parameters known as sum of squares (SS), pure SS, degree of freedom (dof), variance, F-ratio and percentage of each factor. Since the procedure of ANOVA is a very complicated and employs a considerable of statistical formula, only a brief description of is given as following.

The Sum of Squares (SS) is a measure of the deviation of the experimental data from the mean value of the data. Let A be a factor under investigation.

The Sum of Squares (SS) is a measure of the deviation of the experimental data from the mean value of the data. Let A'' be a factor under investigation

$$\text{Formula } SS_T = \sum_{i=1}^n (Y_i - \bar{T})^2$$

Where N = Number of response observations,  $\bar{T}$  is the mean of all observations  $Y_i$  is the  $I_{th}$  response

$$SS_A = \left[ \sum_{i=1}^{Ka} (A_i^2/n_{Ai}) \right] - \frac{T \times T}{N}$$

Where  $A_i$  = Average of all obseravtions under  $A_i$  level =  $A_i / n_{Ai}$

$$T = \text{sum of all observations} = \frac{T}{N}$$

$\bar{T}$  = Average of all observations

$n_{Ai}$  = Number of observations under  $A_i$  level

$$SS_e = \sum_{j=1}^{Ka} \sum_{i=1}^{na} (y_i - \bar{A}_j)^2$$

Error Sum of Squares  $SS_e$ . Squared deviations of observations from factor (A) average

$$SS_{A \times B} = \sum_{i=1}^c \left( \frac{(A \times B)(A \times B)i}{n(A \times B)i} \right) - \frac{T \times T}{N} - SS_A - SS_B$$



**Figure 3.9: Tool used for machining**



**Figure 3.10: Work piece after machining**

### **4.1 INTRODUCTION**

The effects of parameters i.e steam pressure, speed, feed, depth of cut and interaction between steam pressure and speed in rpm were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. One repetition for each of 18 trails was completed to measure the Signal to Noise ratio(S/N Ratio).

### **4.2 RESULTS FOR MRR**

The results for MRR for each of the 18 treatment conditions with repetition are given in Table 5.3.1. MRR of each sample is calculated from weight difference of work piece before and after the performance trial, which is given by:

$$MRR = \frac{(W_i - W_f)}{\rho \times t} \times 1000 \text{ mm}^3 / \text{min} \dots\dots\dots(4.1)$$

Where  $W_i$  = Initial weight of work piece material (gms)

$W_f$  = Final weight of work piece material (gms)

$t$  = Time period of trails in minutes

$\rho$  = Density of work piece in gms/cc

**Table 4.1: Results for MRR**

Experiment No:	Pressure (lb/in <sup>2</sup> )	Speed (rpm)	Feed rate (mm/min)	DOC (mm)	MRR (mm <sup>3</sup> /min)	S/N Ratio	Mean
1	15	450	20	0.50	197.7	45.9201	197.7
2	15	450	35	0.75	369.2	51.3452	369.2
3	15	450	65	1	781	57.8530	781
4	15	900	20	0.50	167.7	44.4907	167.7
5	15	900	35	0.75	409.8	52.2514	409.8
6	15	900	65	1	921.9	59.2937	921.9
7	15	2900	20	0.75	197.8	45.9245	197.8
8	15	2900	35	1	601.5	55.5847	601.5
9	15	2900	65	0.50	717.5	57.1164	717.5
10	25	450	20	1	258.5	48.2492	258.5
11	25	450	35	0.50	238.3	47.5425	238.3
12	25	450	65	0.75	508.1	54.1190	508.1
13	25	900	20	0.75	203.7	46.1798	203.7
14	25	900	35	1	355.4	51.0143	355.4
15	25	900	65	0.50	389.2	51.8035	389.2
16	25	2900	20	1	298.9	49.5105	298.9
17	25	2900	35	0.50	333.2	50.4541	333.2
18	25	2900	65	0.75	898.7	59.0723	898.7

### **4.3 ANALYSIS OF VARIANCE - MRR**

The results for MRR were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean MRR at 95% confidence interval is given in Table 4.2. The variance data for each factor and their interactions were P value to find significance of each. From Table 4.2 pressure (A), feed (C) and depth of cut (D) have the P value less the 0.05 that means these factors are significant. Interaction between pressure and speed has the P value more than the 0.05 that means this factor is insignificant. Speed has value of P more then 0.05 that means it is insignificant. Table 4.3 shows ranks to various input parameters in terms their relative significance.

**Table 4.2: Analysis of Variance for Means of MRR**

Source	SS	v	V	F	P	SS'	% contribution	Status
Pressure (A)	43032	1	43032	4.25	0.050	30076.92	2.90	Significant
Speed (B)	47313	2	23656	2.34	0.159			Insignificant
Feed (C)	720834	2	360417	35.6 3	0.000	694923.84	67.18	Significant
Doc (D)	114984	2	57492	5.68	0.029	89073.84	8.61	Significant
Pressure × Speed (E)	27227	2	13614	1.35	0.313			Insignificant
Residual error	80921	8	10115					
Total	1034311	17					100	
E-pooled	155461	12	12955.08				21.31	

**Table 4.3: Response Table for Means of MRR**

Level	Pressure (A)	Speed (B)	Feed (C)	DOC (D)
1	484.9	392.1	220.7	340.6
2	387.1	408.0	384.6	431.2
3		507.9	702.7	536.2
Delta	97.8	115.8	482.0	195.6
Rank	4	3	1	2

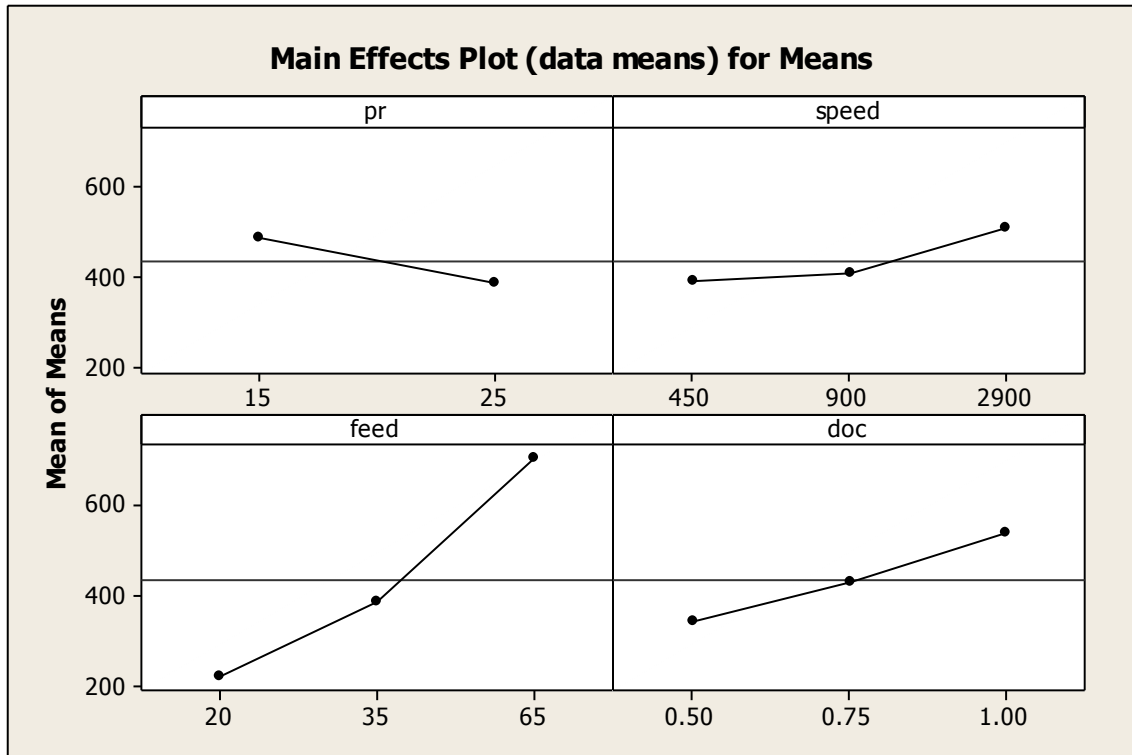


Figure 4.1: Main effect plot of MRR for Means

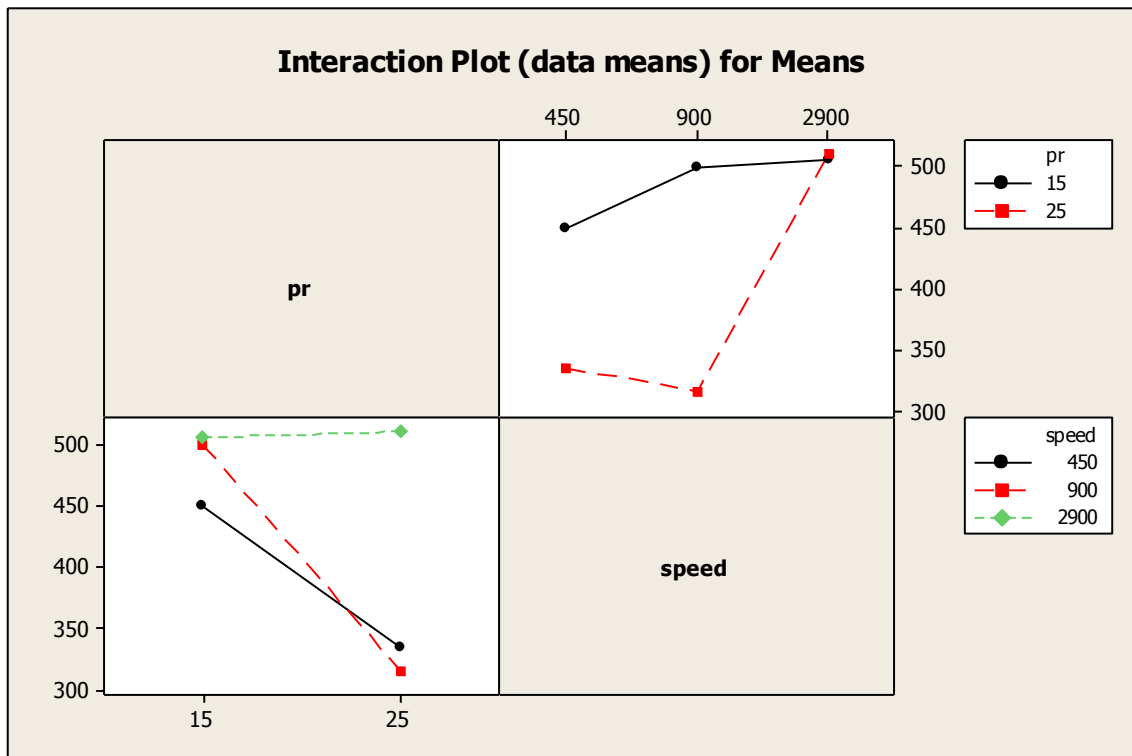


Figure 4.2: Interaction plot for MRR

#### 4.4 RESULTS FOR S/N RATIO- MRR

The S/N ratio consolidates several repetitions into one value and is an indication of the amount of variation present. The S/N ratios have been calculated to identify the major contributing factors and interactions that cause variation in the MRR. MRR is “Higher is better” type response which is given by:

$$(S/N)_{HB} = -10 \log (MSD_{HB}) \dots\dots\dots(4.2)$$

$$\text{Where } MSD_{LB} = \frac{1}{r} \sum_{j=1}^r (1/y_i^2)$$

$MSD_{HB}$ = Mean Square Deviation for higher-the-better response.

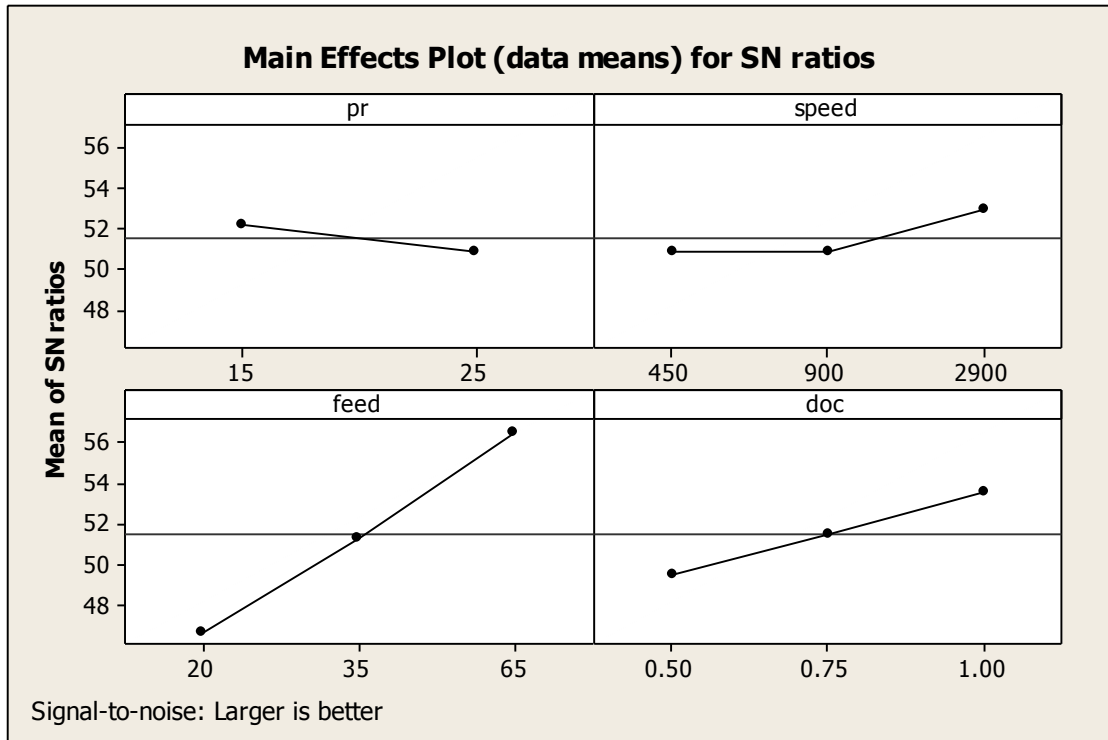
Table 4.4 shows the ANOVA results for S/N ratio of MRR at 95% confidence interval. Feed was observed to be the most significant factor affecting the MRR, followed by depth of cut and speed are significant according to P value. The interactions between pressure and speed is insignificant. Main effects plot and interaction plot of S/N ratio for MRR are shown in the figure 4.3 and 4.4 respectively. Table 4.5 shows ranks to various input parameters in terms their relative significance.

**Table 4.4: Analysis of Variance for S/N ratio of MRR**

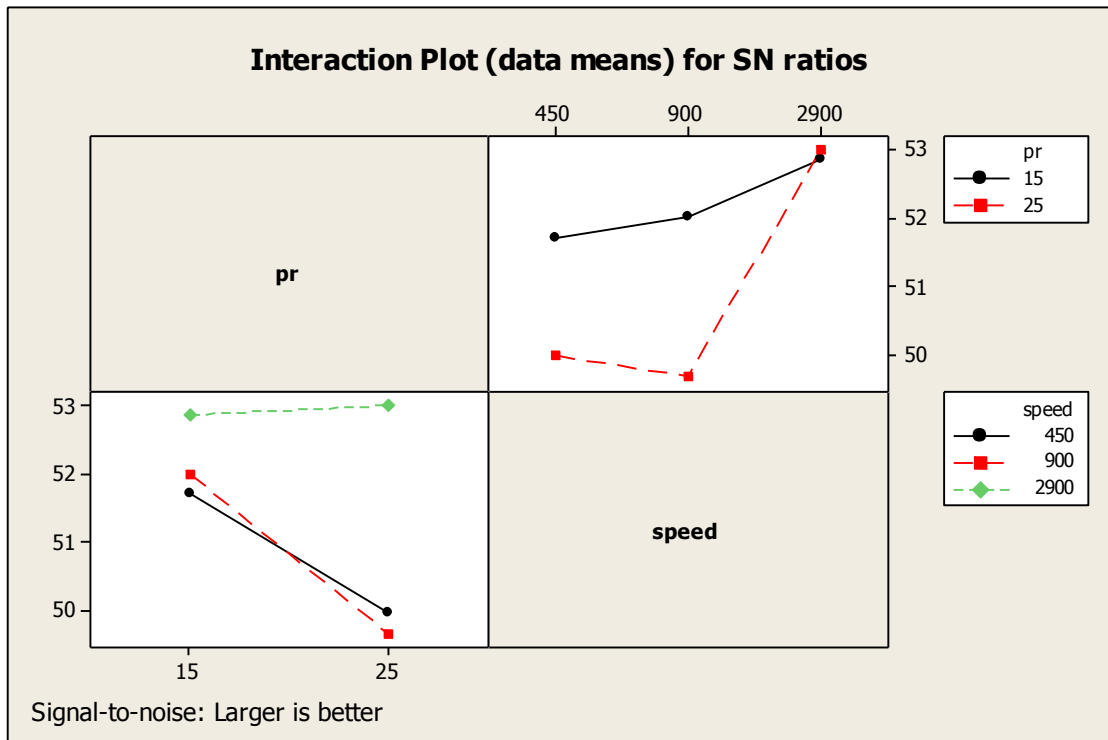
Source	SS	v	V	F	P	SS'	% contribution	Status
Pressure (A)	7.781	1	7.781	3.92	0.083			Insignificant
Speed (B)	17.728	2	8.864	4.46	0.050	12.518	3.24	Significant
Feed (C)	290.191	2	145.096	73.07	0.000	284.981	73.95	Significant
DOC (D)	48.746	2	24.373	12.27	0.004	43.536	11.29	Significant
Pressure × Speed (E)	5.023	2	2.512	1.26	0.333			Insignificant
Residual error	15.885	8	1.986					
Total	385.355	17						
E-pooled	28.689	11	2.60				11.52	

**Table 4.5: Response Table for S/N ratio of MRR**

Level	Pressure (A)	Speed (B)	Feed (C)	DOC (D)
1	52.20	50.84	46.71	49.55
2	50.88	50.84	51.37	51.48
3		52.94	56.54	53.58
Delta	1.31	2.11	9.83	4.03
Rank	4	3	1	2



**Figure 4.3: Main effect plot for MRR of S/N ratio**



**Figure 4.4: Interaction plot for MRR of S/N ratio**

## 4.5 OPTIMAL DESIGN

The same level of all the significant factors provide a higher mean value and reduced variability so nothing has to be compromised. The level of factors which improves average and uniformity may conflict, so a compromise may have to be reached. Also a compromise has to occur when multiple responses are considered and the same factor level may cause one response to improve and other to reduce. In this experimental analysis, the main effect plot in Figure 4.1 is used to estimate the mean MRR with optimal design conditions. In Table 4.6 it is concluded that highest MRR was achieve at feed of 65 mm/min with 1 mm depth of cut and at steam pressure of 15 lb/in<sup>2</sup>. In S/N ratio highest MRR was found at speed of 2900 rpm, feed of 65 mm/min and depth of cut 1mm.

### Estimating the mean

MRR is a “Higher the better” type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of MRR is given by:

$$\begin{aligned} \mu A_1 C_3 D_3 &= A_1 + C_3 + D_3 - 2T \dots\dots\dots(4.3) \\ &= 484.9 + 702.7 + 536.2 - 2 \times 436 \\ &= 851.8 \text{ mm}^3/\text{min} \end{aligned}$$

**Table 4.6: Significant factors and interactions for MRR**

Factor	Affecting mean		Affecting variation	
	contribution	Best level	contribution	Best level
Pressure (A)	significant	level 1(15)	insignificant	
Speed (B)	insignificant		significant	Level 3(2900)
Feed (C)	significant	Level 3(65)	significant	Level 3(65)
Doc (D)	significant	Level 3(1)	significant	Level 3(1)
Pressure * speed (E)	insignificant		insignificant	

### Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean  $\mu$  is only a point estimate based on the averages of results obtained from the experiment.

Confidence Interval around the estimated MRR :

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}} \dots\dots\dots(4.3)$$

Where  $F_{\alpha, v_1, v_2}$  = F ratio

$$= 4.75$$

$\alpha$  = risk (0.05)

confidence =  $1 - \alpha$

$v_1$  = dof for mean which is always = 1

$v_2$  = dof for error

$\eta_{eff}$  = number of test under that condition using the participating factors

$$\eta_{eff} = N / (1 + \text{dof}_{A,C,D}) = 18 / (1 + 1 + 2 + 2) = 3.0$$

$$CI = 143.22$$

So the confidence interval around the MRR is given by  $851.8 \pm 143.22 \text{ mm}^3/\text{min}$ .

## **CHAPTER 5**

### **RESULT AND ANALYSIS OF SURFACE ROUGHNESS**

---

#### **5.1 INTRODUCTION**

Surface roughness of the machined surface of work piece is expressed in microns. The characteristics of the layer of the work material just below the machined surface can also be evaluated. The effect of various parameters such as cutting speed, work piece, feed, drill material, and drill diameter were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. 18 trials were conducted in the experiment using L18 experimental design. One repetition for each of 18 trials was completed to measure Signal to Noise ratio (S/N ratio).

#### **5.2 RESULTS FOR SURFACE ROUGHNESS (R<sub>A</sub>)**

The results for surface roughness are shown in table 5.1 as follows:

**Table 5.1: Results for Surface Roughness (Ra)**

Trail No:	Pressure (lb/in <sup>2</sup> )	Speed (rpm)	Feed rate (mm/min )	DOC (mm)	Surface roughness (μm)	S/N Ratio	Mean
1	15	450	20	0.50	0.28	11.0568	0.28
2	15	450	35	0.75	0.49	6.1961	0.49
3	15	450	65	1	0.71	2.9748	0.71
4	15	900	20	0.50	0.29	10.7520	0.29
5	15	900	35	0.75	0.55	5.1927	0.55
6	15	900	65	1	1.23	-1.7981	1.23
7	15	2900	20	0.75	0.49	6.1961	0.49
8	15	2900	35	1	0.81	1.8303	0.81
9	15	2900	65	0.50	1.14	-1.1381	1.14
10	25	450	20	1	0.37	8.6360	0.37
11	25	450	35	0.50	1.05	-0.4238	1.05
12	25	450	65	0.75	1.08	-0.6685	1.08
13	25	900	20	0.75	0.81	1.7237	0.81
14	25	900	35	1	1.14	-1.1381	1.14
15	25	900	65	0.50	1.41	-2.9844	1.41
16	25	2900	20	1	0.99	0.0873	0.99
17	25	2900	35	0.50	1.17	-1.3637	1.17
18	25	2900	65	0.75	1.01	-0.0864	1.01

Mitutoyo SURFTEST 300

DATE 2000-01-01  
TIME 01:06:54

STAND JIS2001  
PROFILE R  
FILTER GAUSS  
EVA-L 0.24mm  
N 3  
 $\lambda_c$  0.08mm  
 $\lambda_s$  2.5 $\mu$ m  
TILT-COMP. ALL  
CURVE-CMP. OFF  
M-SPEED 0.1mm/s  
R-SPEED 1mm/s  
AUTO-RTN ON  
RANGE 800 $\mu$ m  
 $\pm$ ESC  
DRIVE ON  
STYLUS STAND  
PRE/POST ON

**R-PROFILE**

EVA-L 0.24mm  
 $\lambda_c$  0.08mmX3

Ra 1.16 $\mu$ m  
Rz 5.1 $\mu$ m  
Rq 1.44 $\mu$ m  
Rt 7.7 $\mu$ m

**R-PROFILE**

EVA-L 0.24mm  
 $\lambda_c$  =0.08mmX3  
 $\times$ 5K

$\times$ 500

Ver. 2.0 $\mu$ m/cm  
Hor. 20.0 $\mu$ m/cm

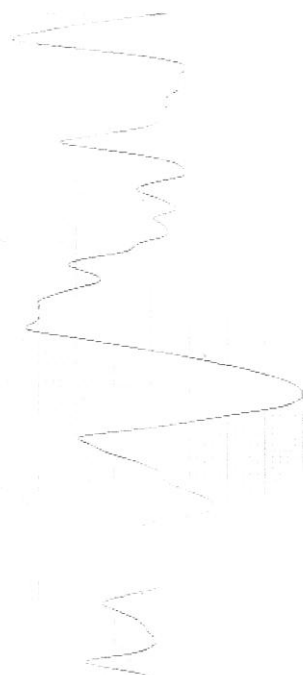


Figure 5.1: Profile of surface roughness of experiment no. 9

### **5.3 ANALYSIS OF VARIANCE - SURFACE ROUGHNESS (Ra)**

The results for SR were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean SR at 95% confidence interval is given in Table 5.2. The variance data for each factor and their interactions were P value to find significance of each. From Table 5.2 pressure, speed, feed have the P value less the 0.05 that means these factor are significant. Depth of cut and interaction between pressure and speed have value more then 0.05 that means it is insignificant. Table 5.3 shows ranks to various input parameters in terms their relative significance.

**Table 5.2 : Analysis of Variance for Roughness of Means**

Source	SS	v	V	F	P	SS'	% contribution	Status
Pressure (A)	0.51681	1	0.51681	15.32	0.004	0.503245	23.93	Significant
Speed (B)	0.26763	2	0.13382	3.97	0.050	0.2405	11.45	Significant
Feed (C)	0.93963	2	0.46982	13.93	0.002	0.9125	43.45	Significant
DOC (D)	0.08190	2	0.04095	1.21	0.346			Insignificant
Pressure*Speed (E)	0.02708	2	0.01354	0.40	0.682			Insignificant
Residual error	0.26980	8	0.03373					
Total	2.10285	17					100	
e-pooled	0.37878	12	0.013565				21.17	

**Table 5.3: Response Table for Roughness of Means**

Level	Pressure (A)	Speed (B)	Feed (C)	DOC (D)
1	0.6656	0.6633	0.5400	0.8900
2	1.0044	0.9067	0.8683	0.7400
3		0.9350	1.0967	0.8750
Delta	0.3389	0.2717	0.5567	0.1500
Rank	2	3	1	4

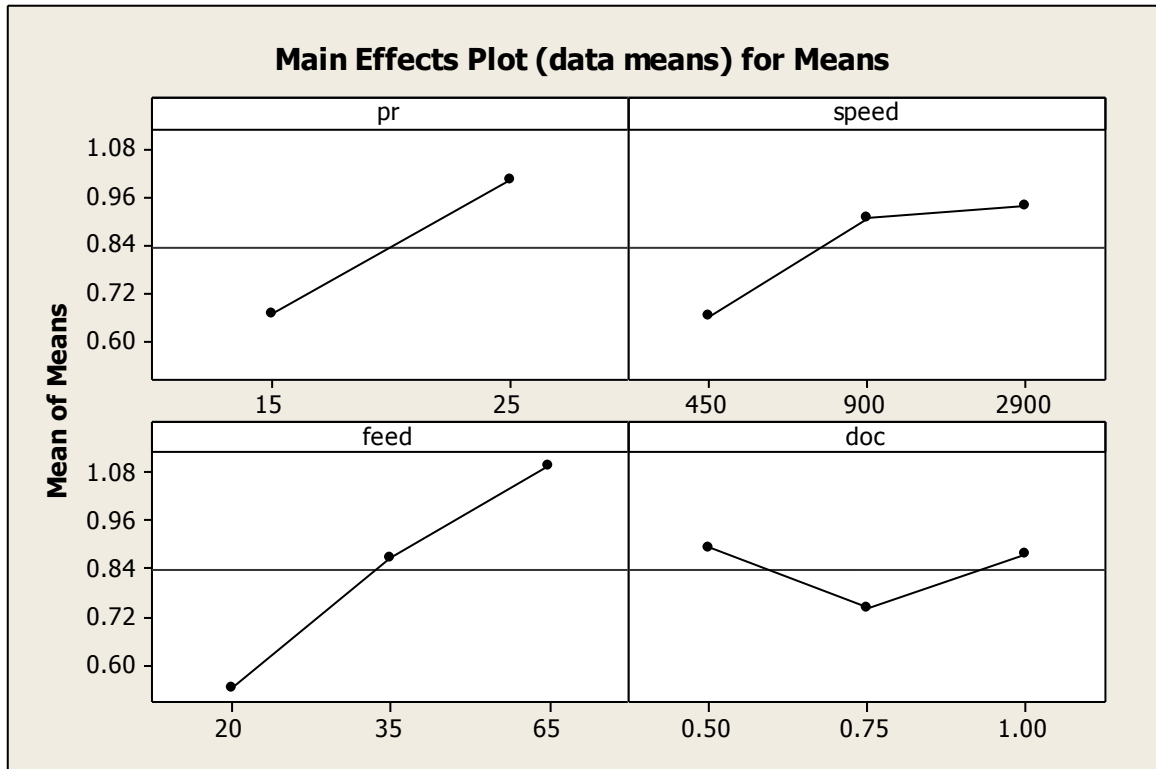


Figure 5.2: Main effects plot for surface roughness of Means

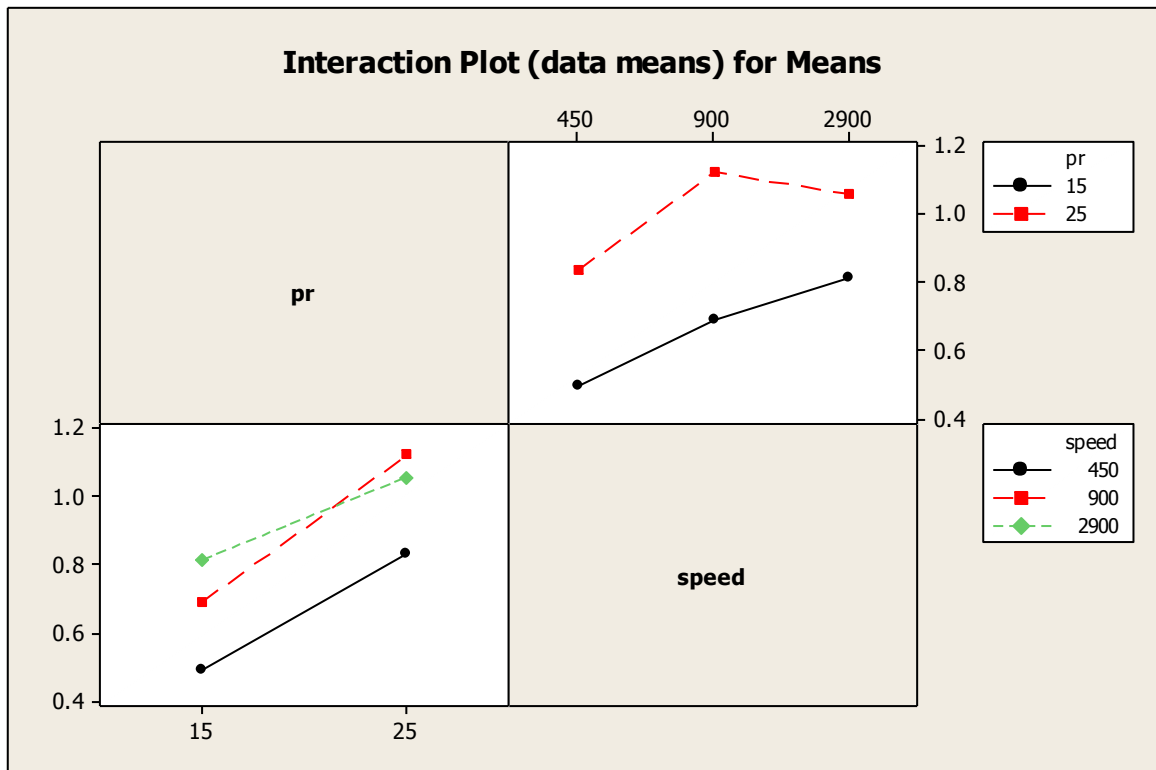


Figure 5.3: Interaction plot surface roughness of Means

## 5.4 RESULTS FOR S/N RATIO – SURFACE ROUGHNESS

The S/N ratio is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors that cause variation in surface roughness. Surface roughness is a “lower the better” type response and it is given by a logarithmic function based on the mean square deviation:

$$S / N_{LB} = -10 \log(MSD) = -10 \log\left(\frac{1}{r} \sum_{i=1}^r y^2_i\right)$$

Where  $MSD_{LB} = \frac{1}{r} \sum_{j=1}^r (y_j^2)$  .....(5.1)

$MSD_{LB}$ = Mean Square Deviation for lower -the-better response.

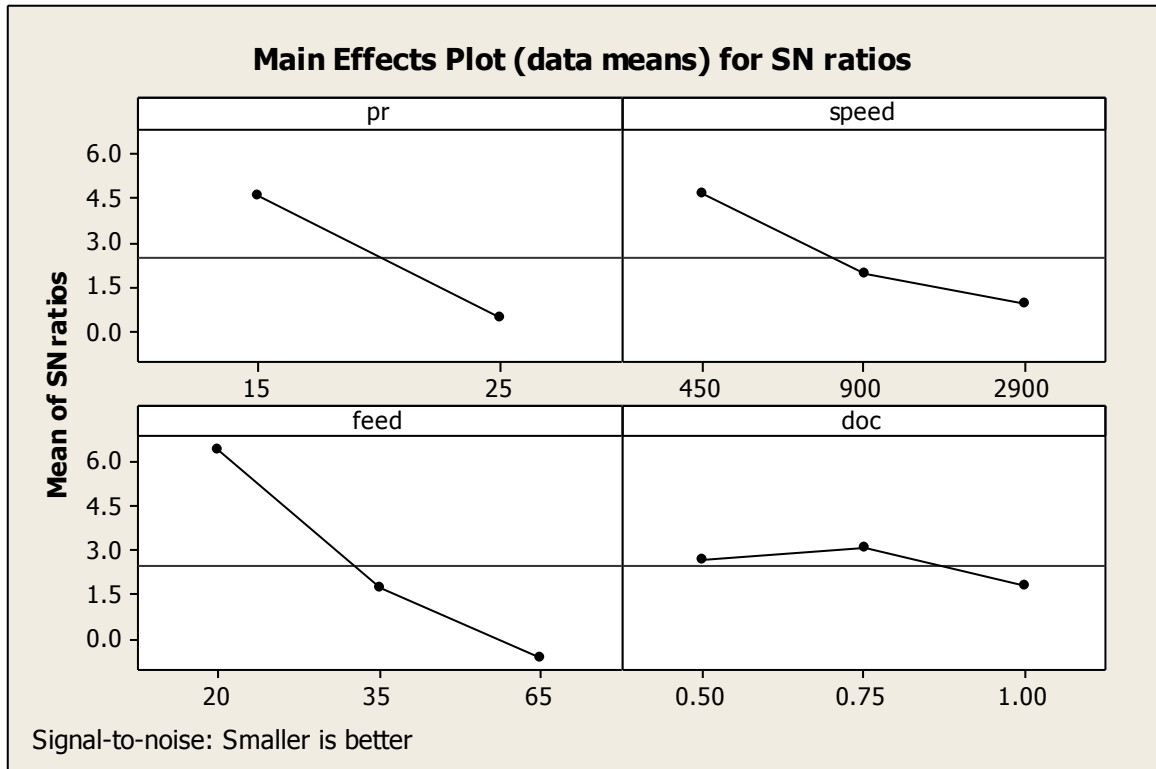
Table 5.4 shows the ANOVA results for S/N ratio of Surface roughness at 95% confidence interval. Pressure, speed and feed are the factors, which are found to be significant. Main effect plot of S/N ratio for Surface roughness are shown in the Figure 5.4. Table 5.5 shows the ranks of various factors in the terms of their relative significance. Feed has the highest rank, which signifies that it provides highest contribution to Surface roughness and depth of cut has the lowest rank and was found to be insignificant in affecting Surface roughness. Interaction plot of S/N ratio for Surface roughness are shown in the figure 5.5.

**Table 5.4 Analysis of Variance FOR S/N ratio for roughness (Ra)**

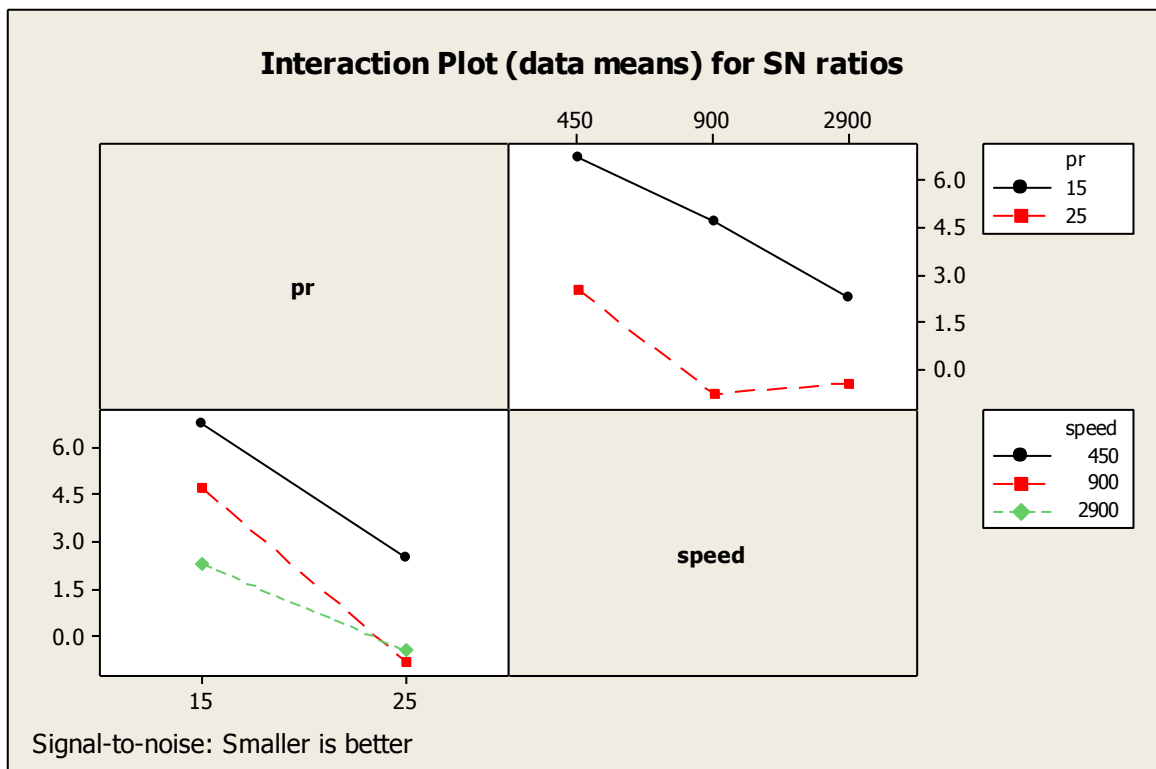
Source	SS	v	V	F	P	SS'	% contribution	Status
Pressure (A)	78.044	1	78.044	12.73	0.007	73.0215	21.74	Significant
Speed (B)	43.909	2	21.954	3.58	0.050	33.864	10.08	Significant
Feed (C)	153.643	2	76.822	12.53	0.003	143.598	42.75	Significant
DOC (D)	5.478	2	2.739	0.45	0.655			Insignificant
Pressure*Speed (E)	5.742	2	2.871	0.47	0.642			Insignificant
Residual error	49.050	8	6.131					
Total	335.866	17					100	
E-pooled	60.27	12	5.0225				25.43	

**Table 5.5: Response Table for S/N Ratios for roughness (Ra)**

Level	Pressure (A)	Speed (B)	Feed (C)	DOC (D)
1	4.5847	4.6286	6.4087	2.6498
2	0.4202	1.9580	1.7156	3.0923
3		0.9209	-0.6168	1.7654
delta	4.1645	3.7077	7.0254	1.3269
Rank	2	3	1	4



**Figure 5.4: Main effects plot for surface roughness of S/N ratio**



**Figure 5.5: Interaction plot for of S/N ratio for surface roughness**

## 5.5 OPTIMAL DESIGN

In this experimental analysis, the main effect plot in Figure 5.2 is used to estimate the mean surface roughness with optimal design conditions. In Table 5.6 it is concluded that minimum surface roughness was achieved when 15 lb/in<sup>2</sup>, speed of 450 rpm and feed of 20 mm/min was selected in the experiment trial. In S/N ratio minimum surface roughness was achieved under pressure of 25 lb/in<sup>2</sup>, speed of 2900 rpm and feed of 65 mm/min mean. In this case, the same levels of the significant factors provide the higher average and reduced variability, hence nothing has to be compromised. In some case, the levels of factors which improve the average and improve the uniformity may conflict which means compromise may have to be reached. Moreover, a compromise may have to occur when multiple responses are considered and the same level factor may cause one response to improve and another to reduce.

### Estimating the mean

Surface roughness is a “lower the better” type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of surface roughness is given by:

$$\begin{aligned} \mu_{A_1B_1C_1} &= A_1 + B_1 + C_1 - 2T \dots\dots\dots(5.2) \\ &= 0.6656 + 0.6633 + 0.5400 - 2 \times 0.83 \\ &= 0.2089 \mu\text{m} \end{aligned}$$

### Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean  $\mu$  is only a point estimate based on the averages of results obtained from the experiment.

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}} \dots\dots\dots(5.3)$$

**Table 5.6: Significant factors and interactions for surface roughness**

Factor	Affecting mean		Affecting variation	
	Contribution	Best level	contribution	Best level
Pressure (A)	Significant	Level 1 (15)	significant	Level 2 (25)
Speed (B)	significant	Level 1 (450)	significant	Level 3(2900)
Feed (C)	significant	Level 1(20)	significant	Level 3(65)
Doc (D)	insignificant		insignificant	
Pressure * speed	insignificant		insignificant	

Where  $F_{\alpha v_1 v_2} = F$  ratio

4.75

$\alpha = \text{risk (0.05)}$

confidence =  $1 - \alpha$

$v_1 = \text{dof for mean which is always=1}$

$v_2 = \text{dof for error}$

$\eta_{\text{eff}} = \text{number of test under that condition using the participating factors}$

$\eta_{\text{eff}} = N / (1 + \text{dof}_{A,B,C}) = 18 / (1 + 1 + 2 + 2) = 3.0$

CI = 0.146

Thus, the confidence interval around the estimated mean of surface roughness is given by  $0.2089 \pm 0.146 \mu\text{m}$ .

## **CHAPTER 6**

### **RESULT AND ANALYSIS OF SURFACE HARDNESS**

---

#### **6.1 INTRODUCTION**

The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. In this test, measurement is made on a B scale at load of 100 kgf.

#### **6.2 RESULTS FOR HARDNESS**

The results for hardness for each of the 18 treatment conditions with repetition are given in Table 6.1.

**Table: 6.1 Result for surface hardness**

Trail No:	Pressure (lb/in <sup>2</sup> )	Speed (rpm)	Feed rate (mm/min)	DOC (mm)	Surface Hardness (HRB)	S/N Ratio	Mean
1	15	450	20	0.50	77.0	37.7298	77.0
2	15	450	35	0.75	77.5	37.7860	77.5
3	15	450	65	1	78.0	37.8419	78.0
4	15	900	20	0.50	77.0	37.7298	77.0
5	15	900	35	0.75	78.0	37.8419	78.0
6	15	900	65	1	78.5	37.8974	78.5
7	15	2900	20	0.75	79.0	37.9525	79.0
8	15	2900	35	1	79.5	38.0073	79.5
9	15	2900	65	0.50	78.0	37.8419	78.0
10	25	450	20	1	79.5	38.0073	79.5
11	25	450	35	0.50	77.0	37.7298	77.0
12	25	450	65	0.75	78.5	37.8974	78.5
13	25	900	20	0.75	79.0	37.9525	79.0
14	25	900	35	1	80.5	38.1159	80.5
15	25	900	65	0.50	80.0	38.0618	80.0
16	25	2900	20	1	80.0	38.0618	80.0
17	25	2900	35	0.50	79.5	38.0073	79.5
18	25	2900	65	0.75	80.0	38.0618	80.0

### **6.3 ANALYSIS OF VARIANCE – HARDNESS**

The results for Hardness were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean Hardness at 95% confidence interval is given in Table 6.2. The variance data for each factor and their interactions were P value to find significance of each. From Table 6.2 pressure, speed and depth of cut have the P value less the 0.05 that means these factor are significant. Feed and interaction between pressure and speed have value more then 0.05 that means it is insignificant. Table 6.3 shows ranks to various input parameters in terms their relative significance.

**Table 6.2: ANOVA for mean of hardness**

Source	SS	v	V	F	P	SS'	% contribution	Status
Pressure (A)	7.3472	1	7.34722	24.05	0.001	7.0278	31.844	Significant
Speed (B)	6.1944	2	3.09722	10.14	0.006	5.5556	25.1733	Significant
Feed (C)	0.1944	2	0.09722	0.32	0.736			Insignificant
DOC (D)	4.6944	2	2.34722	7.68	0.014	4.0556	18.3765	Significant
Pressure*Speed (E)	1.1944	2	0.59722	1.95	0.204			Insignificant
Residual error	2.4444	8	0.30556					
Total	22.0694	17					100	
e-pooled	3.8332	12	0.3194				24.6062	

**Table 6.3: Response table for means of hardness**

Level	Pressure (A)	Speed (B)	Feed (C)	DOC (D)
1	78.06	77.92	78.58	78.08
2	79.33	78.83	78.67	78.67
3		79.33	78.83	79.33
delta	1.28	1.42	0.25	1.25
rank	2	1	4	3

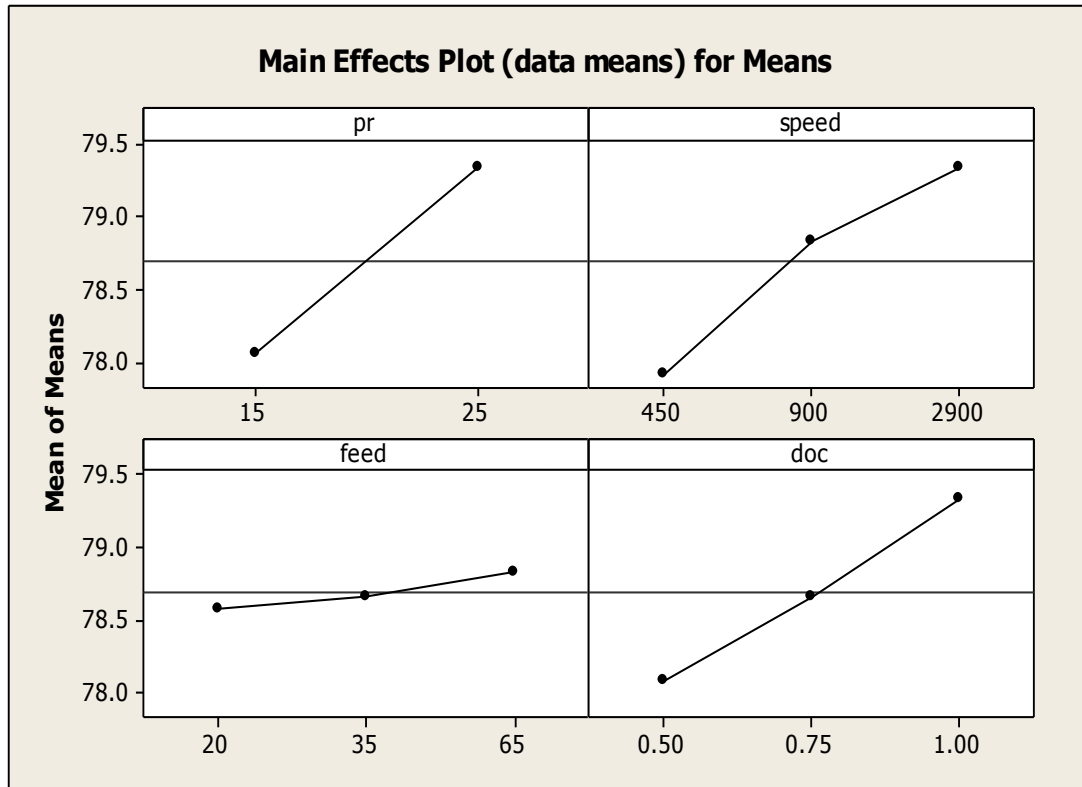


Figure 6.1: Main effect plot for Mean hardness

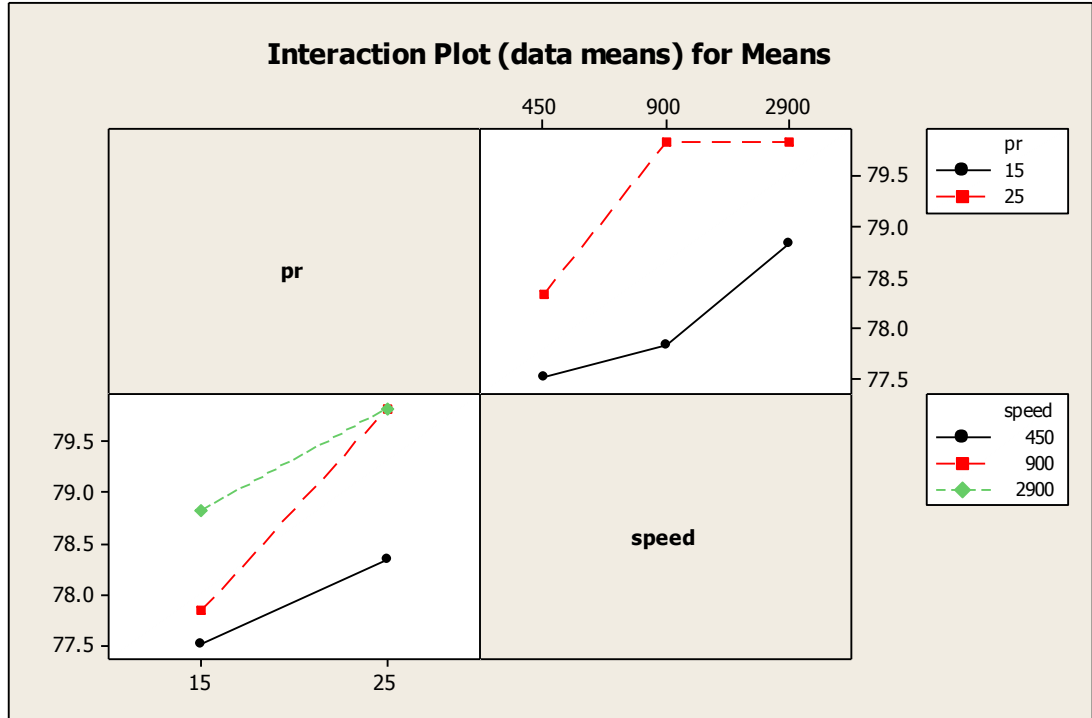


Figure 6.2: Interaction plot for Mean hardness

#### 6.4 RESULTS FOR S/N RATIO – HARDNESS

The S/N ratio consolidates several repetitions into one value and is an indication of the amount of variation present. The S/N ratios have been calculated to identify the major contributing factors and interactions that cause variation in the hardness. Hardness is “Higher is better” type response which is given by:

$$(S/N)_{HB} = -10 \log (MSD_{HB}) \dots\dots\dots(6.1)$$

$$\text{Where } MSD_{LB} = \frac{1}{r} \sum_{j=1}^r (1/y_j^2)$$

*MSD<sub>HB</sub>*= Mean Square Deviation for higher-the-better response.

Table 6.4 shows the ANOVA results for S/N ratio of hardness at 95% confidence interval. Pressure was observed to be the most significant factor affecting the hardness, followed by speed and depth of cut are significant according to P value. The interactions between pressure and speed is insignificant. Main effects plot and interaction plot of S/N ratio for MRR are shown in the figure 6.3 and 6.4 respectively. Table 6.5 shows ranks to various input parameters in terms their relative significance.

**Table 6.4: ANOVA for S/N ratio of hardness**

Source	SS	V	V	F	P	SS'	% contribution	Status
Pressure (A)	0.0892	1	0.0892	23.90	0.001	0.0854	31.70	Significant
Speed (B)	0.0757	2	0.0378	10.15	0.006	0.0681	25.27	Significant
Feed (C)	0.0024	2	0.0012	0.33	0.729			Insignificant
DOC (D)	0.0576	2	0.0288	7.72	0.014	0.05	18.55	Significant
Pressure*Speed (E)	0.0144	2	0.0072	1.94	0.206			Insignificant
Residual error	0.0298	8	0.0037					
Total	0.2694	17					100	
e-pooled	0.0466	12	0.0038				24.48	

**Table 6.5: Response table for means of hardness**

Level	Pressure (A)	Speed (B)	Feed (C)	DOC (D)
1	37.85	37.83	37.91	37.85
2	37.99	37.93	37.91	37.92
3		37.99	37.93	37.99
Delta	0.14	0.16	0.03	0.14
Rank	2	1	4	3

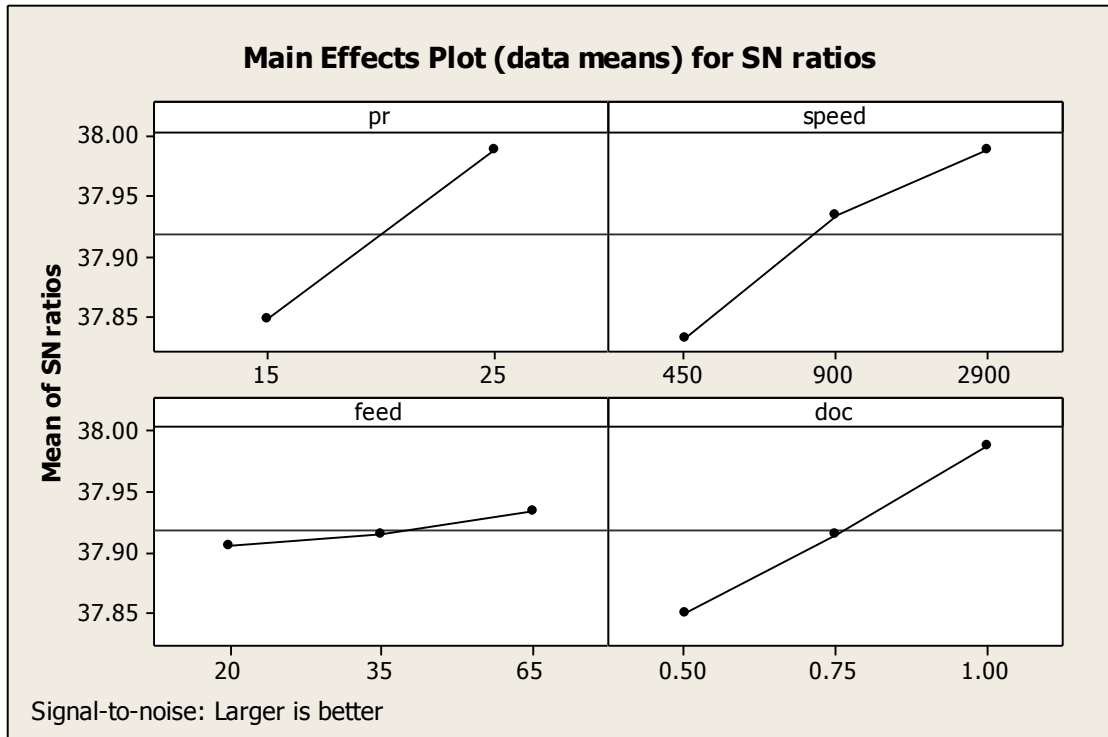


Figure 6.3: Main effects plot for of S/N ratio of hardness

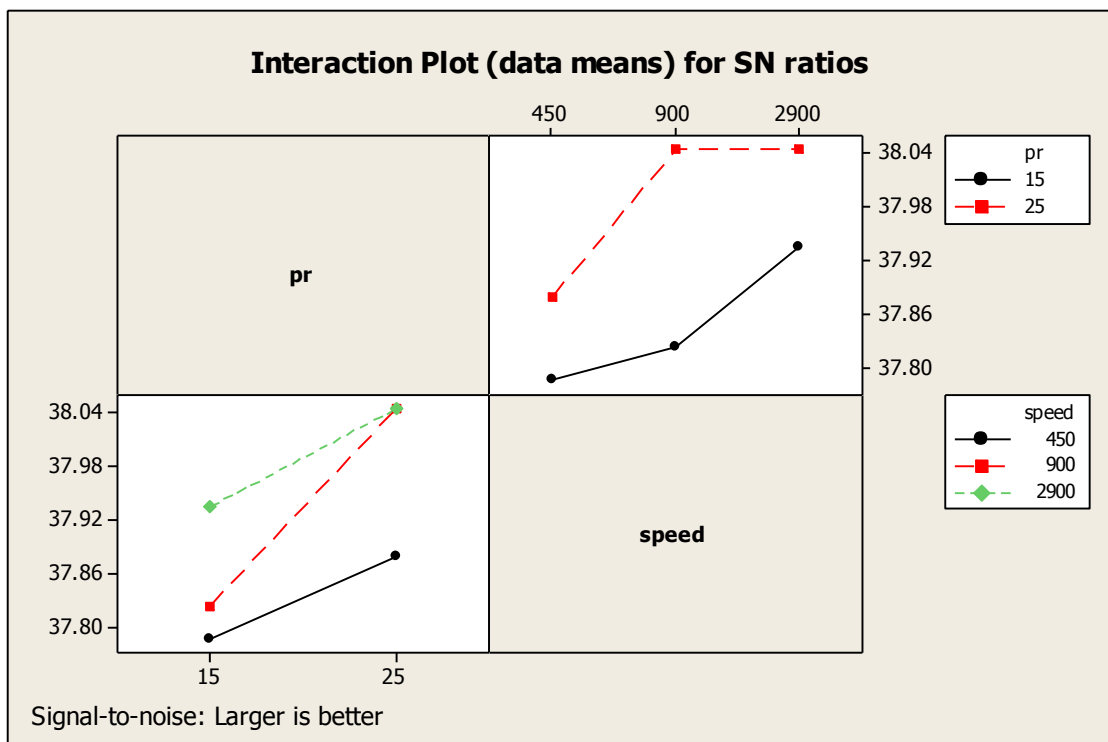


Figure 6.4: Interaction plot for of S/N ratio of hardness

## 6.5 OPTIMAL DESIGN

The same level of all the significant factors provide a higher mean value and reduced variability so nothing has to be compromised. The level of factors which improves average and uniformity may conflict, so a compromise may have to be reached. Also a compromise has to occur when multiple responses are considered and the same factor level may cause one response to improve and other to reduce. In this experimental analysis, the main effect plot in Figure 6.1 is used to estimate the mean hardness with optimal design conditions. In Table 6.6 it is concluded that highest hardness was achieved at speed of 2900 rpm with 1 mm depth of cut and at steam pressure of 25 lb/in<sup>2</sup>. In S/N ratio highest hardness was found under same parameters.

### Estimating the mean

Hardness is a “Higher the better” type response. In this experiment analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments, the optimum treatment condition within the experiments determined based on prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of hardness is given by:

$$\begin{aligned} \mu_{A_2B_3D_3} &= A_2 + B_3 + D_3 - 2T \dots\dots\dots(6.2) \\ &= 79.33 + 79.33 + 79.33 - 2 * 78.69 \\ &= 80.61 \end{aligned}$$

**Table 6.6: Significant factors and interactions for hardness**

Factor	Affecting mean		Affecting variation	
	contribution	Best level	contribution	Best level
Pressure (A)	significant	level 2 (25)	significant	Level 2 (25)
Speed (B)	significant	Level 3 (2900)	significant	Level 3(2900)
Feed (C)	insignificant		insignificant	
Doc (D)	significant	Level 3(1)	significant	Level 3(1)
Pressure * speed (E)	insignificant		insignificant	

### Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean  $\mu$  is only a point estimate based on the averages of results obtained from the experiment.

Confidence Interval around the estimated hardness :

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}} \dots\dots\dots(6.3)$$

Where  $F_{\alpha, v_1, v_2}$  = F ratio

4,75

$\alpha$  = risk (0.05)

confidence =  $1 - \alpha$

$v_1$  = dof for mean which is always = 1

$v_2$  = dof for error

$n_{eff}$  = number of test under that condition using the participating factors

$n_{eff} = N / (1 + dof_{A,B,C}) = 18 / (1 + 1 + 2 + 2) = 3.0$

C.I = 0.71

So the confidence interval around the hardness is given by  $80.61 \pm 0.71$  HRB.

7.1 INTRODUCTION

A statistical procedure used to find relationships among a set of variables. In regression analysis, there is a **dependent variable**, which is the one you are trying to explain, and one or more **independent variables** that are related to it. You can express the relationship as a linear equation, such as:

y = a + bx .....(7.1)

- y is the dependent variable
- x is the independent variable
- a is a constant
- b is the slope of the line

For every increase of 1 in x, y changes by an amount equal to b.

Regression finds the line that best fits the observations. It does this by finding the line that results in the lowest sum of squared errors. Since the line describes the mean of the effects of the independent variables, by definition, the sum of the actual errors will be zero. If you add up all of the values of the dependent variable and you add up all the values predicted by the model, the sum is the same. That is, the sum of the negative errors (for points below the line) will exactly offset the sum of the positive errors (for points above the line). Summing just the errors wouldn't be useful because the sum is always zero. So, instead, regression uses the sum of the squares of the errors. An Ordinary Least Squares (OLS) regression finds the line those results in the lowest sum of squared errors.

Multiple Regressions

When, several factors affecting the independent variable. Each of these factors has a separate relationship with the price of a home. The equation that describes a multiple regression relationship is:

y = a + b1x1 + b2x2 + b3x3 + ... bnxn + e .....(7.2)

This equation separates each individual independent variable from the rest, allowing each to have its own coefficient describing its relationship to the dependent variable.

**“p-values” and Significance Levels**

Each independent variable has another number attached to it in the regression result its “p-value” or significance level. The p-value is a percentage. It tells you how likely it is that the coefficient for that independent variable emerged by chance and does not describe a real relationship. p-value of .05 means that there is a 5% chance that the relationship emerged randomly and a 95% chance that the relationship is real. It is generally accepted practice to consider variables with a p-value of less than .1 as significant, though the only basis for this cut off is convention.

The regression equation =  $b_0 + b_1 pr + b_2 speed + b_3 feed + b_4 doc + e$  .....(7.4)

The regression equation for MRR is

$MRR = - 158 - 9.78 A + 0.0481 B + 10.7 C + 391 D + e$  .....(7.5)

$R^2 = 0.89$

The regression equation for hardness is

$Hardness = 73.4 + 0.133 A + 0.000562 B + 0.00476 C + 2.33 D + e$  .....(7.6)

$R^2 = 0.80$

The regression equation for surface roughness is

$Surface\ roughness = - 0.403 + 0.0339 A + 0.000082 B + 0.0117 C - 0.030 D + e$ ..(7.7)

$R^2 = 0.72$

Where A = Pressure

B = Speed

C = Feed

D = Depth of cut

In multiple linear regression analysis, ( $R^2 > 0.80$ ) for the models, which indicate that the fit of the experimental data is satisfactory.

## CHAPTER 8

### RESULT AND CONCLUSIONS

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#### 8.1 RESULTS

The effect of parameters i.e. steam pressure, cutting speed, feed rate, depth of cut and interaction effect between pressure and cutting speed were evaluated using ANOVA design analysis and Regression analysis. The purpose of the ANOVA was to identify the important parameters in prediction of MRR, surface roughness and hardness. Some results consolidated from ANOVA and plots are given below:

##### 8.1.1 MRR

The effect of parameters i.e. steam pressure, cutting speed, feed rate, depth of cut and interaction effect between pressure and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. One repetition for each 18 trails was completed to measure the Signal to Noise ratio (S/N Ratio).

ANOVA table shows that feed with F value 35.63, depth of cut with F value 5.68 and pressure with F value 4.25 are the factors that significantly affect the MRR, with % contribution of 67.18%, 8.61% and 2.90% to MRR.

The other factor speed and pressure  $\times$  speed were found to be insignificant. For S/N ratio cutting speed, feed and depth of cut were significant to reduce the variation of MRR.

With 95% confidence interval mean value of MRR was found to be  $851.8 \pm 143.22 \text{ mm}^3/\text{min}$ .

##### 8.1.2 SURFACE ROUGHNESS

The effect of parameters i.e. steam pressure, cutting speed, feed rate, depth of cut and interaction effect between pressure and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. One repetition for each 18 trails was completed to measure the Signal to Noise ratio (S/N Ratio). In this experiment work surface roughness (Ra) has measured at position center.

ANOVA table shows that feed with F value 13.93, pressure with F value 15.32 and speed with F value of 3.92 are the factors that significantly affect the surface roughness with % contribution of 43.42 %, 23.93 % and 11.45 % to surface roughness.

The other factor depth of cut and pressure  $\times$  speed were found to be insignificant. For S/N ratio pressure, cutting speed and feed were significant to reduce the variation of surface roughness.

With 95% confidence interval mean value of surface roughness was found to be  $0.2089 \pm 0.146 \mu\text{m}$ .

### **8.1.3 SURFACE HARDNESS**

The effect of parameters i.e. steam pressure, cutting speed, feed rate, depth of cut and interaction effect between pressure and cutting speed were evaluated using ANOVA and factorial design analysis. A confidence interval of 95% has been used for the analysis. One repetition for each 18 trails was completed to measure the Signal to Noise ratio (S/N Ratio). Hardness was measured on Rockwell hardness tester on B scale.

ANOVA table shows that pressure with F value 24.05, speed with F value 10.14 and depth of cut with F value 7.68 are the factors that significantly affect the surface hardness with % contribution of 31.84 %, 25.17 % and 18.37 % to surface hardness.

The other factor feed and pressure  $\times$  speed were found to be insignificant. For S/N ratio pressure, cutting speed and depth of cut were significant to reduce the variation of surface hardness.

With 95% confidence interval mean value of surface hardness was found to be  $80.61 \pm 0.71 \text{ HRB}$

## **8.2 CONCLUSIONS**

The present study was carried out to study the effect of input parameters on the MRR, surface roughness and surface hardness. The following conclusions have been drawn from the study:

- MRR is mainly affected by feed rate, depth of cut and pressure.
- Surface roughness is mainly affected by feed rate, steam pressure and cutting speed.
- Surface hardness is mainly affected by steam pressure , cutting speed and depth of cut.

### **8.3 SCOPE FOR FUTURE WORK**

With increasing competitiveness as observed in recent times, manufacturing system in the industry are being driven more and more aggressively. So there is always need for perpetual improvements. Thus for getting more accurate results we can take into account few more parameters as given below:

1. CNC machines can be used for the experimentation to have the better control of the process variables and also parameters can be set to the desired accuracy.
2. The present work can be extended with different diameter of milling tools, process parameters, material thickness and type of tests.
3. Further research can be extended on temperature measurements.
4. Fuzzy logic approach can be used for analysis for have better results.

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## APPENDIX-A

### SPECIFICATIONS OF VERTICAL MILLING MACHINE

1. Machine Number 883/2/90
2. Machine type VM-25-A
3. Manufacturers New Bharat Engineering Works Pvt Ltd (Jamnagar)
4. Motor number 807 (3-phase)
5. Horse power of driving motor 0.75/1 HP
6. Voltage 415 volt
7. Current 1.3/1.9 amp
8. Cycles 50
9. RPM

A	102	204	340	450
B	680	900	1450	2900

10. Depth of cuts (mm) 0, 0.25, 0.5, 0.75, 1, 1.25

11. Feed (mm/min)

A	20	35	65
B	100	175	315