

# **Multi Objective Optimization of Cutting Parameters in Turning Operation to Reduce Surface Roughness and Cutting Forces**

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By

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Certificate of Approval

This is to certify that the thesis entitled **Multi Objective Optimization of Cutting Parameters in Turning Operation to Reduce Surface Roughness and Cutting Forces** submitted by *Sri Suryansh Choudhury* has been carried out under my supervision in partial fulfillment of the requirements for the Degree of *Bachelor of Technology* in *Mechanical Engineering* at National Institute of Technology, Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Suryansh Choudhury

## ABSTRACT

Turning is one the most important machining operation in industries. The process of turning is influenced by many factors such as the cutting velocity, feed rate, depth of cut, geometry of cutting tool cutting conditions etc. The finished product with desired attributes of size, shape, and surface roughness and cutting forces developed are functions of these input parameters. Properties wear resistance, fatigue strength, coefficient of friction, lubrication, wear rate and corrosion resistance of the machined parts are greatly influenced by surface roughness. Forces developed during cutting affect the tool life hence the cost of production. In many manufacturing processes engineering judgment is still relied upon to optimize the multi-response problem. Therefore multi response optimization is used in this study to optimization problem to finds the appropriate level of input characteristics.

The objective of this project is to evaluate the optimal setting of cutting parameters cutting velocity (N) , depth of cut(d) , feed(f) and variation in principal cutting edge angle ( $\Phi$ ) of the tool to have a minimum cutting force and surface roughness( $R_a$ )

In this project dry turning of aluminium 6061 as a work piece and carbide insert tool (SCMT 09T308-TN5120) is performed. The range of cutting parameters are cutting speed(11.86, 18.65,30.52m/min) ,feed rate(0.044,0.089,0.178 mm/rev), depth of cut(0.5,0.75,1.0mm) and the angle (0,3,6 degree)

This study highlights the use of Fuzzy logic and use of Taguchi design of experiment to optimize the multi response in turning operation. For this purpose Taguchi design of experiment was carried out to collect the data for surface roughness and various cutting forces. The results indicate the optimum values of the input factors and the results are conformed by a confirmatory test

## Contents

<b>Chapter No.</b>	<b>Description</b>	<b>Page no.</b>
	Acknowledgement	i
	ABSTRACT	ii
	List of Tables	iv
	List of figures	v
Chapter 1		
1.1	INTRODUCTION AND LITERATURE REVIEW	1
1.2	Objective of the work	8
Chapter 2		
2.1	Cutting Tool Specification	9
2.2	Composition of work piece	10
2.3	Dynamometer	12
2.4	Talysurf	14
2.5	Procedure followed	
chapter 3		
3.1	Fuzzy Inference System (FIS)	18
3.2	Taguchi method	19
CHAPTER 4		
4.1	Experimental observation & Analysis	21
chapter 5		
5.1	Conclusions	30
5.2	Future possibilities	31
	Bibliography	32

## List of Tables

<b>Table No.</b>	<b>description</b>	<b>page no</b>
Table 2.1	Specification of cutting tool	9
Table 2.2	composition of aluminium 6061	12
Table 2.3	mechanical properties of Al 6061	12
Table 2.4	Taguchi design of experiment	16
Table 4.1	observation table	21
Table 4.2	Domain of experiments	23
Table 4.3	Design of experiment and collected data	23
Table 4.4	Computation of S/N ratios	24
Table 4.5	Normalized S/N ratios	24
Table 4.6	Fuzzy rule matrix	26
Table 4.7	Computed MPCl values and corresponding S/N ratios	28
Table 4.8	Response table for S/N ratios of MPCl	29

## List of figures

<b>Figure No.</b>	<b>Description</b>	<b>Page no.</b>
Figure 1.1	Nomenclature of a single point cutting tool	4
Figure 1.2	Effect of tool geometry on performance parameters in turning	5
Figure 1.3	machining process and the principal cutting-tool elements	5
Figure 1.4	Cutting angles	6
Figure 2.1	carbide insert	9
Figure 2.2	handysurf	14
Figure 2.3	stylus based instruments	14
Figure 2.4	measurement of $R_a$	15
Figure 2.5	workpiece	17
Figure 3.1	fuzzy inference system	19
Figure 4.1	Fuzzy inference tipper	25
Figure 4.2	Membership function	25
Figure 4.3	fuzzy rule viewers	26
Figure 4.4	Computation of MPCl	27
Figure 4.5	Fuzzy inference surface plot	27
Figure 4.6	S/N ratio plot for MPCl (Evaluation of optimal setting)	28

# CHAPTER 1

## 1. INTRODUCTION AND LITERATURE REVIEW

### 1.1.

Turning is one of the most main manufacturing processes in metal removal. Black [1] defined metal cutting as the removal of metal chips from a work piece in order to obtain a finished product with desired characteristics of size, shape, and surface roughness. The challenge that the engineers face is to find out the optimal parameters for the preferred output and to maximize the output by using the available resources.

Optimization of cutting parameters is usually a difficult work [2] where the following aspects are required: awareness of machining; empirical equations relating the tool life, forces, power, surface finish, etc. to develop realistic constrains; specification of machine tool capabilities; development of an effective optimization criterion; and knowledge of mathematical and numerical optimization techniques[3].

Usually, the selection of appropriate machining parameters is difficult and relies heavily on the operators' experience and the machining parameters tables

provided by the machine-tool builder for the target material. Hence, the optimization of operating parameters is of great importance where the economy and quality of a machined part play a key role [4]

Recognizing the need to reduce the cost and improve quality and productivity, companies have initiated total quality management. It is a ground-breaking method requiring management commitment, employee involvement, and the use of statistical tools. The method of Dr. Taguchi, employing design of experiments (DOE), is one of the most important statistical tools of TQM for designing high-quality systems at reduced cost. Taguchi methods provide a cost effective, efficient and systematic way to optimize designs for performance, quality, and cost. This method has been used successfully in designing reliable, high-quality products at low cost in such areas as automotive, aerospace, and consumer electronics [5].

Cutting forces and surface roughness are among the most important technical parameters in machining process [6]. Cutting forces are necessary for evaluation of power machining (choice of the electric motor). They are also used for design of machine tool components and the tool body. Cutting forces influences the deformation of the work piece machined, its dimensional accuracy, machine stability and chip formation.

Similarly, the surface quality is a central parameter to evaluate the productivity of machine tools as well as machined components. Hence, achieving the desired surface quality is of great importance for the functional behavior of the mechanical parts [7].

Surface roughness has influence on several properties such as wear resistance, fatigue strength, coefficient of friction, lubrication, wear rate and corrosion resistance of the machined parts [8]. Surface roughness describes the surface geometry and the texture of the surface. Prediction of surface roughness is a complex process and hence left to the machine operators to use their experience for best possible surface roughness.

The surface finish can be characterized by two main parameters, average roughness ( $R_a$ ) and maximum peak to valley height ( $R_t$ ). Theoretical models have been proposed to estimate these parameters and are given as [9]

$$a. \quad R_a(\mu m) = \frac{1000f^2}{32R}$$

$$b. \quad R_t(\mu m) = \frac{1000f^2}{8R}$$

## SINGLE POINT CUTTING TOOL

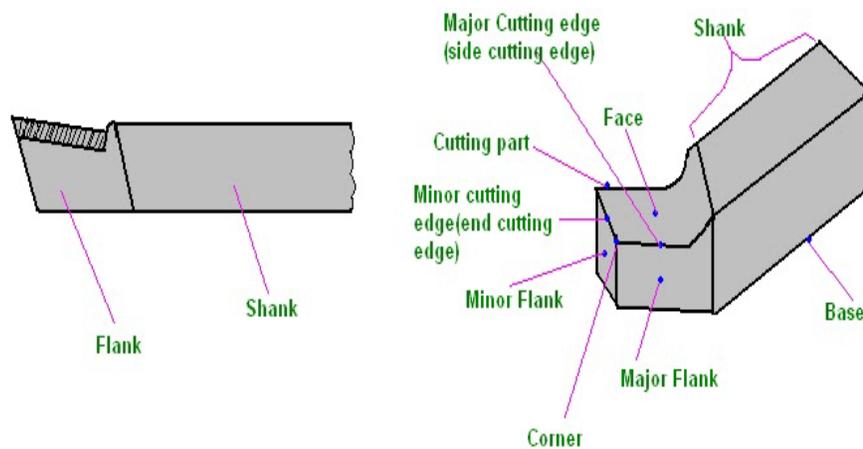


Figure 1.1 Nomenclature of a single point cutting tool [10]

The design of cutting edge geometry and its influence on machining performance has been a research topic in the area of metal cutting for long time. Edge preparation has a significant effect on the tool life. A tool with improper edge fails quickly.[10]It is important to consider the tool-edge effect in order to better understand the chip formation mechanism and accurately predict machining performances, such as cutting forces, cutting temperatures, tool wear, surface finish and the machined surface integrity.

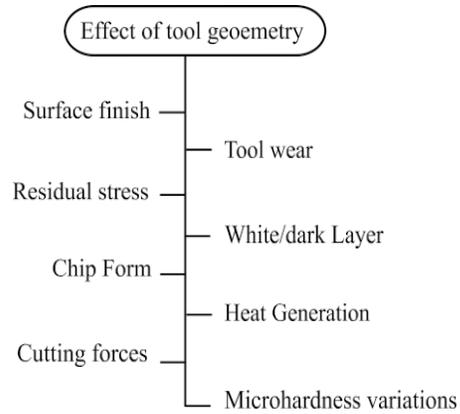


Figure 1.2 Effect of tool geometry on performance parameters in turning [11]

The cutting part consists of the working surfaces (Fig. 1.1). It includes the top surface (face), along which the chip formed in the machining process comes off; and the side relief and end relief surfaces, which face the machined surface of the workpiece. The intersections of the working surfaces form the cutting edges.

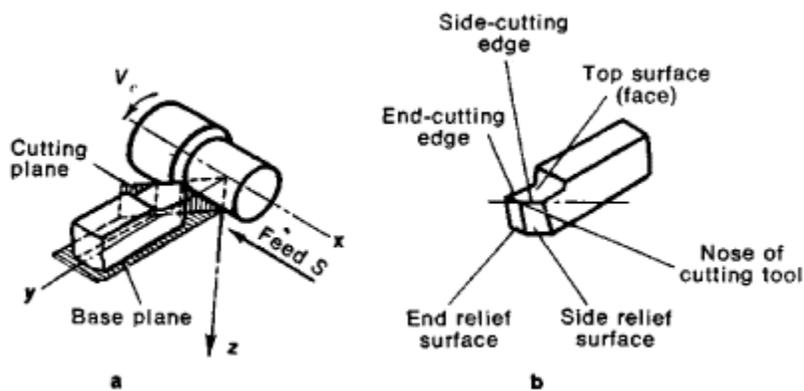


Figure 1.3 Diagram of the machining process (a) and the principal cutting-tool elements [12]

The side-cutting edge, which performs the primary work during machining, is formed by the intersection of the top and the side relief surfaces. The end-cutting edge is formed by the intersection of the side relief and end relief surfaces. The point at which the side and end-cutting edges converge is called the tool point or the nose. It is the weakest part of the tool and decides the overall strength of the cutting edge. As a result, in order to increase its strength, the tool point is given a cutting edge that is circular (with a radius of 0.5-2 mm) or is in the form of a transitional cutting edge (0.5-3 mm long).

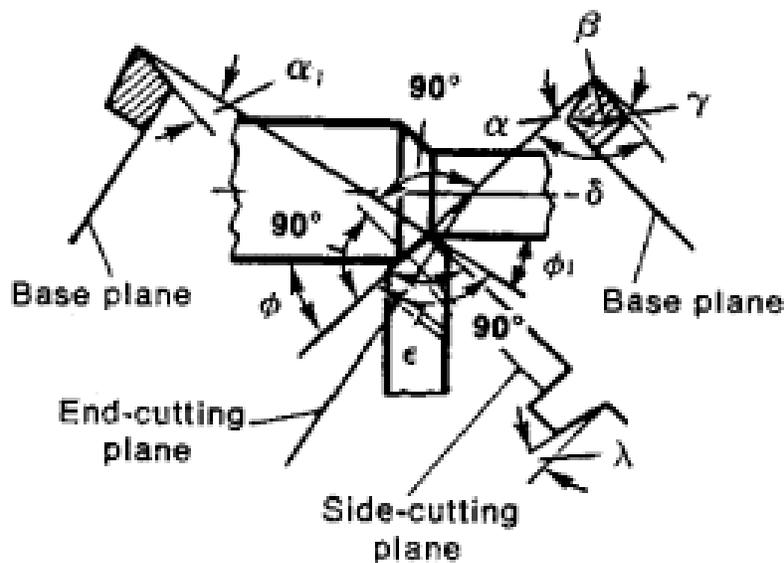


Figure 1.4 Cutting angles

The angle between the side relief surface of the tool and the machining plane is called the side relief angle  $\alpha$ . choice of a relief angle depends upon the rate of feed to avoid friction between the relief surface of the tool and the machined and cutting surfaces: the bigger the feed, the larger the relief angle. The lip angle  $\beta$  is the angle between the top and the side relief surfaces of the tool. The side rake

angle  $\gamma$  is the angle between the plane perpendicular to the cutting plane and the top surface of the tool. The selection of the rake angle depends mainly on the physical and mechanical properties of the material being machined. Larger rake angle results in the easier process of formation of chips but this lowers the cutting force, resulting in lesser power consumption. For hard materials, cutting tool with smaller rake angle is used. The cutting angle  $\delta$  is the angle between the top surface of the tool and the cutting plane. The primary angle in the plane  $\phi$  is the angle between the feed direction and the projection of the side-cutting edge on the base plane; the secondary angle in the plane  $\phi_1$  is the angle between the feed direction and the projection of the end-cutting edge on the base plane. The angles  $\phi$  and  $\phi_1$  determine on the one hand the operating conditions of the cutting edge and on the other hand the distribution of the load from the cutting forces. The smaller the angle in the plane, the lower the thermal and force loadings per unit length of the side-cutting edge keeping feed and depth of cut constant, resulting in better operating conditions. Reduction in the angle in the plane below the optimal value may result in too much deformation of the workpiece being machined, inaccurate machining, and vibrations.  $\epsilon$  the nose angle is the angle between the projections of the cutting edges on the base plane:  $\epsilon = 180^\circ - (\phi + \phi_1)$ . The rake angle  $\lambda$  of the side-cutting edge is the angle between the cutting edge and the line drawn through the nose of the cutting tool parallel to the base plane;  $\lambda$  is positive when the nose of the tool is the lowest point of the cutting edge, it is negative when the nose is the highest point, and is zero when the side-cutting edge is parallel to the base plane. [13]

## **1.2. Objective of the work**

The purpose of this paper is to study the effect of various cutting parameters to identify the optimum surface roughness and cutting forces using Taguchi method for multi objective optimization.

# CHAPTER 2

## 2. Brief description of apparatus used

### 2.1. Cutting Tool Specification

**CUTTING TOOL:** Tool is carbide insert tool SCMT 09T308 TN5120 (ISO catalog number

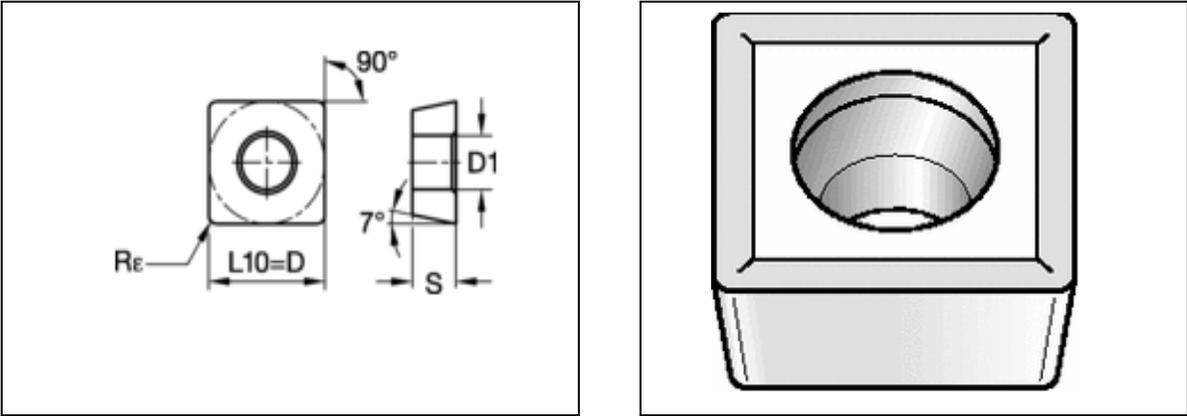


Figure 2.1 carbide insert

ISO catalog number	Tip	Dimensions (mm)				
		D	L10	S	Rε	D1
SCMT 09T308 TN5120	Carbide	9,53	9,53	3,97	0,8	4,40

Table 2.1 Specification of cutting tool

## 2.2. Composition of work piece

Aluminum is the third most abundant element (after oxygen and silicon), and the most abundant metal, in the Earth's crust. It makes up about 8% by weight of the Earth's solid surface. Aluminium is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. Aluminum is a relatively soft, durable, lightweight, ductile and malleable Metal. Aluminum has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded. Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical. Aluminum is capable of being a superconductor. Corrosion resistance can be excellent due to a thin surface layer of aluminium oxide that forms when the metal is exposed to air, effectively preventing further oxidation.

Aluminum is the most widely used non-ferrous metal. Global production of aluminium in 2005 was 31.9 million tonnes. It exceeded that of any other metal except iron.

**6061** is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S" it was developed in 1935. It has good

mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use

6061 is widely used for construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft.

- 6061 is used for yacht construction, including small utility boats.
- 6061 is commonly used in the construction of bicycle frames and Components.
- 6061 is used in automotive parts, such as wheel spacers.
- 6061 is used in the manufacture of aluminium cans for the Packaging of food stuffs and beverages.[14]

Composition	
Element	Weight %
<u>Al</u>	97.9
<u>Si</u>	0.60
<u>Cu</u>	0.28
<u>Mg</u>	1.0
<u>Cr</u>	0.20

Table 2.2 composition of aluminium 6061

Properties		Conditions	
		T (°C)	Treatment
Density ( $\times 1000 \text{ kg/m}^3$ )	2.7	25	
Poisson's Ratio	0.33	25	
Elastic Modulus (GPa)	70-80	25	
Yield Strength (Mpa)	48	25	O (Alclad) more
Elongation (%)	25		
Reduction in Area (%)			
Hardness (HB500)	30	25	O more
Shear Strength (MPa)	83	25	O more
Fatigue Strength (MPa)	62	25	O more

Table 2.3 mechanical properties of Al 6061[15]

### 2.3. Dynamometer

Machining is still one of the most important ways of shaping both metallic and non metallic parts. During machining the cutting tool exerts force on the work piece and similar force is experienced by the tool too. Empirical relationship to estimate the cutting forces are no

more relied upon to determine the optimum cutting condition. Optimization of cutting parameters requires accurate measurement of forces for which we use a device called dynamometer. It is capable of measuring components of forces in a particular coordinate system. It is a useful tool with wide application in manufacturing and research.

A satisfactory dynamometer design involves a compromise between a structure that allows highest possible sensitivity at sufficient stiffness and rigidity so that the geometry of the cutting process is maintained. At the same time the dynamometer structure should maintain a high natural frequency to minimize chattering. Cutting forces cannot be measured directly. Whenever a force acts on a material it undergoes a certain deformation, which can be measured and hence the acting force can be accordingly derived. Therefore, the principle on which all the dynamometers are designed is to measure the deflection or strains induced in the dynamometer structure caused by the resultant cutting force. Dynamometer designs differ depending on whether the deflections of the structure are measured directly with displacement transducers or whether the induced strains in the structure are measured by strain gauges and their associated equipment of high sensitivity, which allows sufficient stiffness to the structure.[16]

## 2.4. Talysurf

Handysurf is a hand held device used for measuring surface roughness values. It is a stylus based instrument. Stylus instruments are based on the principle of running a probe across a surface in order to detect variations in height as a function of distance.



Figure 2.2 handysurf

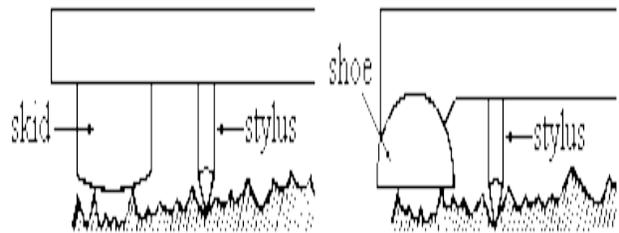


figure 2.3 stylus based instruments

The next step in the development of the stylus instruments was to incorporate a transducer, which converted vertical displacement into an electrical signal. This signal can then be processed by the instrument electronics to calculate a suitable roughness. The type of transducer used largely affects instrument performance. A piezoelectric crystal is often used as the transducer in the less expensive instruments. Other transducer mechanisms include moving coil transducers, capacitance transducers, and linear variable differential transformers (LVDT). Some error can be introduced in roughness measurements when a stylus

instrument is used because of several factors. Some of these factors are the size of the stylus, stylus load, stylus speed, and lateral deflection by asperities.[17]

**Surface roughness**

**Center line average roughness – ( $R_a$ )**

The most common roughness parameter is the average roughness,  $R_a$ . This is also referred to as the arithmetic average or the centerline average (CLA). Its designates as  $R_a$

The average roughness ( $R_a$ ) reports the average distance between the surface and the mean line looking at all of the points along the profile.

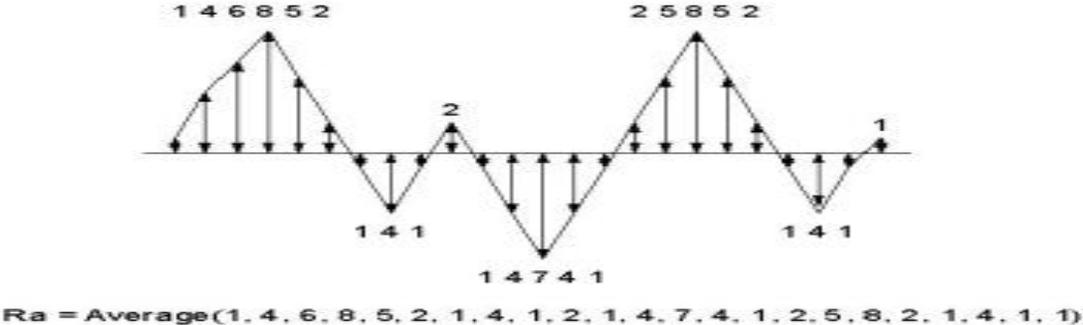


Figure 2.4 measurement of  $R_a$

## 2.5. Procedure followed

Tool used : SCMT 09T308 TN5120

Material used : Aluminium 6061

Dynamometer : for measuring forces

Handysurf : for measuring surface roughness value.

The workpiece of the length of around 3 ft was centered and fixed on the headstock properly. . Then according to the design of experiment table 2.4 the cutting parameters and principal cutting edge angle are adjusted in the lathe machine. The workpiece was given initial roughing pass. Nine equal parts of 25mm are marked equally on the workpiece. Taking the different parameters and changing principal cutting edge angle readings are taken for analysis. Taguchi design of experiment was used to decide the level of the parameters being used.

sample no.	Factorial settings (Coded)			
	Cutting speed	Depth of cut	Feed rate	Primary cutting edge angle
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2.4 Taguchi design of experiment

The tool was fixed to the dynamometer which was fixed to the tool post. Talysurf was used to measure the  $R_a$  value for each machined surface. Analysis of the data was done using Taguchi optimization using fuzzy logic.



Fig 2.5 workpiece

### 3. Methodology

#### 3.1. Fuzzy Inference System (FIS)

Fuzzy inference or fuzzy ruled based system consists of 4 parts

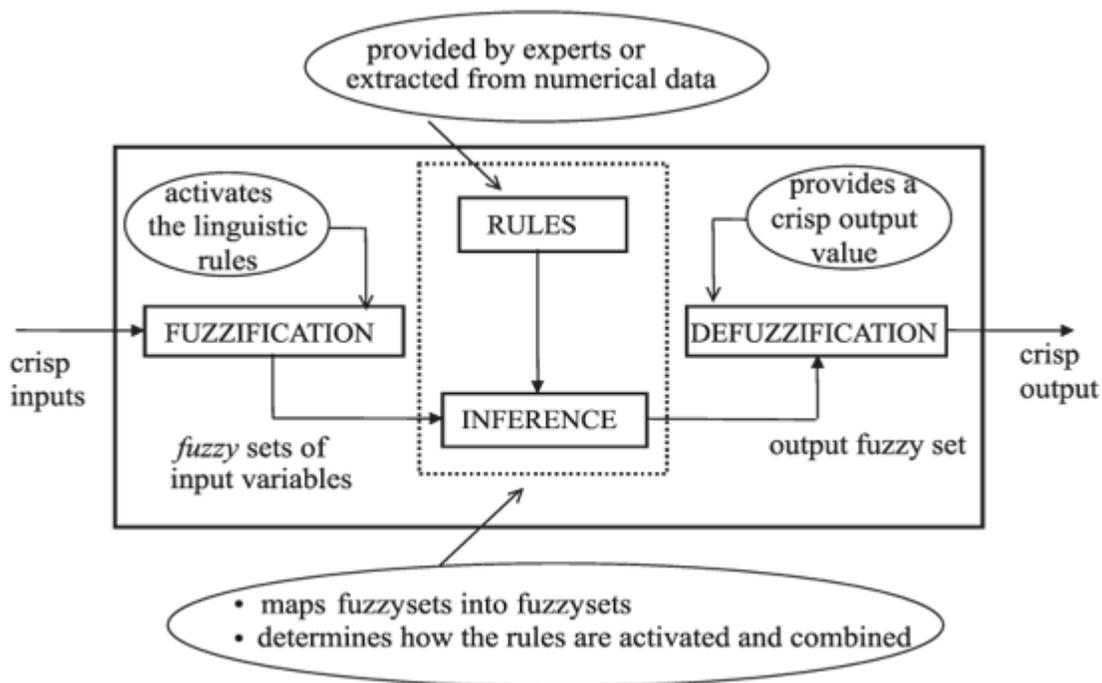
- a) Fuzzification interface
- b) A rule base and database
- c) A decision making unit
- d) Defuzziication interface.

Detail study of fuzzy can be found in various texts.[18]

The functions of the above are:

- rule base consisting a number of fuzzy IF–THEN rules and the database which defines the membership functions of the fuzzy sets used in the fuzzy rules;
- decision-making unit which performs the inference operations on the rules;
- A fuzzification interface which converts the crisp inputs into degrees of match with linguistic values;
- A defuzzification interface which converts the fuzzy results of the

## Inference into a crisp output



**Fig 3.1 fuzzy inference system[19]**

### 3.2. Taguchi method

Taguchi methods are statistical methods developed to improve the quality of manufactured goods and more recently also applied to engineering, biotechnology, marketing and advertising[20].The work of Taguchi includes three principal contributions to statistics:

- A specific loss function , Taguchi loss function;
- The philosophy of off-line quality control; and
- Innovations in the design of experiments.

Taguchi philosophy is mostly used in engineering optimization processes. It should be carried in three step approach i.e. system design, parameter design, tolerance design. In system design involves, scientific and engineering principles and know-how are used to create a prototype of the product that will meet functional requirements. In Parameter design we optimize the settings of process parameter values for improving performance characteristics and in tolerance design, tolerances are set about the target value of the control parameter identified in the parameter design phase and is done only when the performance variation achieved by the settings recognized in the parameter design stage is not satisfactory. [21] Taguchi also defined a performance measure known as the signal to noise ratio (S/N) and aims to maximize it by properly selecting the parameter levels.

Nominal is the best:

$$S/NT = 10 \log \left( \frac{\bar{y}}{s^2} \right)$$

Larger is the better (maximize):

$$S/NL = -10 \log \frac{1}{y} \sum_{i=1}^n \frac{1}{y_i^2}$$

Smaller is better (minimize):

$$S/NS = -10 \log \frac{1}{y} \sum_{i=1}^n y_i^2$$

Where  $\bar{Y}$  the average of observed data is,  $Sy^2$  is the variance of y, n the no of observations and Y is the observed data.

## CHAPTER 4

### 4. Experimental observation & Analysis

The resultant force and surface roughness data was collected according to the Taguchi analysis method of the Minitab 14<sup>®</sup> software. Minitab 14 software was used as it provides an easy method to generate, alter and revise graphs. Also it provides a active link between a graph and its worksheet thus helps in updating the graph automatically whenever the data is altered. Its appearance and simple to use enhancements further add to its usefulness.[22]

Cutting Velocity(m/min)	Depth Of Cut(mm)	Feed(mm/rev)	Principal cutting edge angle	Force(Kg)			resultant	Ra( $\mu$ m)
				Thrust	Feed	Radial		
11.86	0.5	0.044	74	5	2	3	6.164414	1.2
11.86	0.75	0.089	71	10	4	5	11.87434	3.6
11.86	1	0.178	68	25	10	13	29.89983	8.2
18.65	0.5	0.089	68	7	2	3	7.874008	2
18.65	0.75	0.178	74	20	6	13	24.59675	9.4
18.65	1	0.044	71	9	4	6	11.53256	2
30.52	0.5	0.178	71	14	4	8	16.61325	7.8
30.52	0.75	0.044	68	6	3	3	7.348469	1
30.52	1	0.089	74	16	8	12	21.54066	3.4

Table 4.1 observation table

Data analysis has been carried out by the procedural hierarchy as shown below:

- Computation of (Signal-to-Noise Ratio) S/N ratio of experimental data table 4.1 has been done. For calculating S/N ratio of Ra and force a Lower-the-Better (LB) criterion has been selected.
- S/N ratios have been normalized based on Higher-the-Better (HB) criterion.(table 4.5)
- The Normalized S/N ratios corresponding to individual responses have been fed as inputs to a Fuzzy Inference System (FIS). For each of the input parameters three Triangular type membership functions (MFs) have been chosen as: Low (L), Medium (M) and High (H). Based on fuzzy association rule mapping (Table 4.6) .FIS combined multiple inputs into a single output termed as Multi-Performance Characteristic Index (MPCI). The linguistic valuation of MPCI has been represented by Five Triangular type membership functions (MFs) have been chosen as: Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH). These linguistic values haven transformed into crisp values by defuzzification method.
- The crisp values of MPCI (Table 4.7) have been optimized by using Taguchi philosophy. The predicted optimal setting has been evaluated from *Mean Response Plot* of MPCIs and it became A3 B1 C1 D2
- Optimal setting has been verified by confirmatory test.

Factors	Symbol and unit	Code	Levels of Factors		
			1	2	3
Cutting speed	N(m/min)	A	11.86	18.65	30.52
Depth of cut	d(mm)	B	0.5	0.75	1
Feed rate	f(mm/rev)	C	0.044	0.089	0.178
Principal cutting edge angle	$\Phi$ (degree)	D	74	71	68

Table 4.2 Domain of experiments

Factorial settings (Coded)				Experimental data		MPCI Crisp Values
A	B	C	D	resultant force	R <sub>a</sub> ( $\mu$ m)	
1	1	1	1	1.732051	1.2	0.895
1	2	2	2	3.464102	3.6	0.649
1	3	3	3	5.196152	8.2	0.181
2	1	2	3	3.741657	2	0.758
2	2	3	1	3.741657	9.4	0.21
2	3	1	2	3.741657	2	0.706
3	1	3	2	3.741657	7.8	0.396
3	2	1	3	3.741657	1	0.873
3	3	2	1	3.741657	3.4	0.525

Table 4.3 Design of experiment and collected data

Sl. No.	S/N ratio for force	S/N ratio for R <sub>a</sub> (dB)
1	-15.7978	-1.5836
2	-21.4922	-11.1261
3	-29.5134	-18.2763
4	-17.9239	-6.0206
5	-27.8176	-19.4626
6	-21.2385	-6.0206
7	-24.4091	-17.8419
8	-17.3239	0
9	-26.6652	-10.6296

Table 4.4 Computation of S/N ratios

Sl. No.	S/N ratio for force	S/N ratio for R <sub>a</sub> (dB)
1	1	0.918633687
2	0.584823121	0.428334344
3	0	0.060952802
4	0.84498673	0.69065798
5	0.123640234	0
6	0.603320307	0.69065798
7	0.372152877	0.083272533
8	0.888732538	1
9	0.207661349	0.45384481

Table 4.5 Normalized S/N ratios

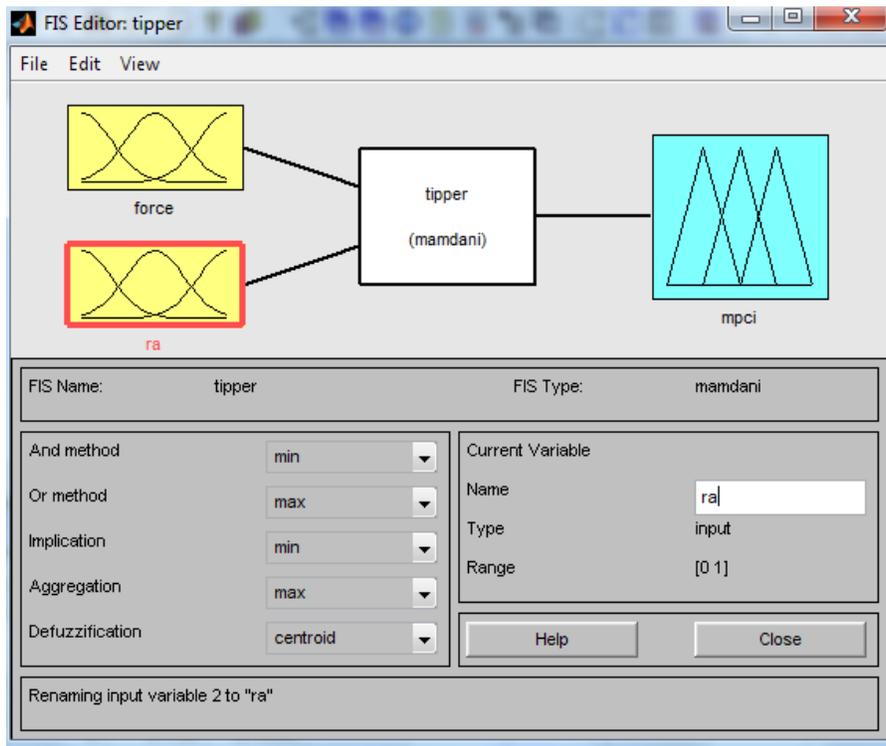


Figure 4.1 Fuzzy inference tipper

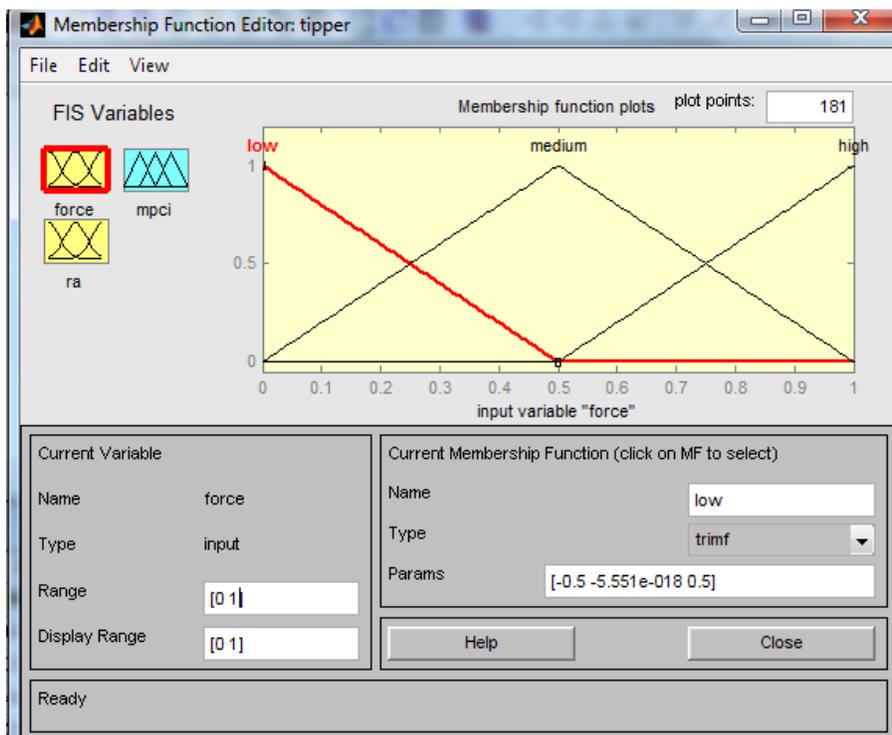


Figure 4.2 Membership function

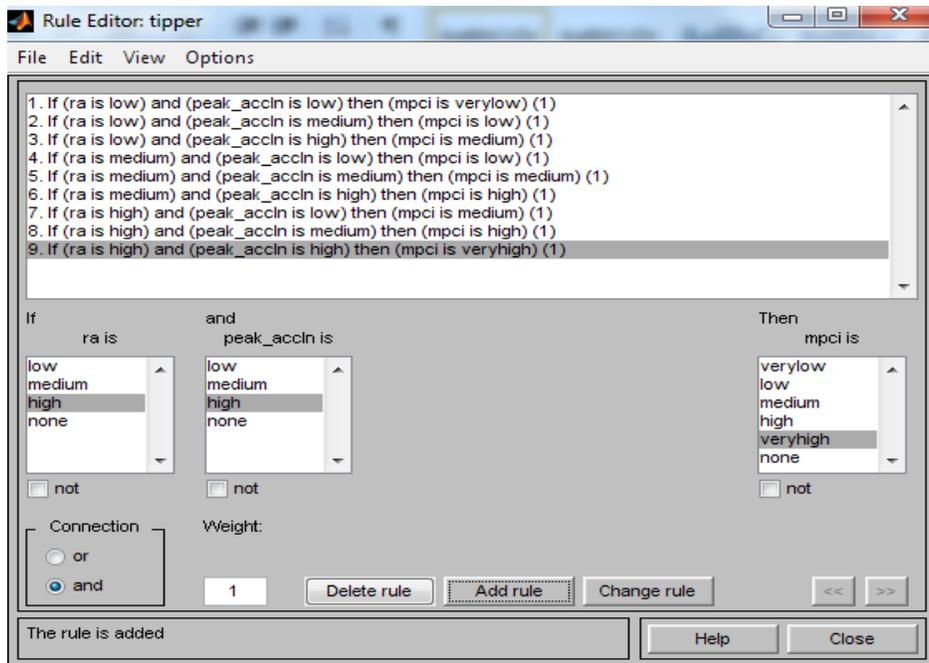


Figure 4.3 fuzzy rule viewers

MPCI	Normalized S/N Ratio of			
	Ra			
Normalized S/N Ratio of force	L	VL	L	M
	M	L	M	H
	H	M	H	VH

Table 4.6 Fuzzy rule matrix

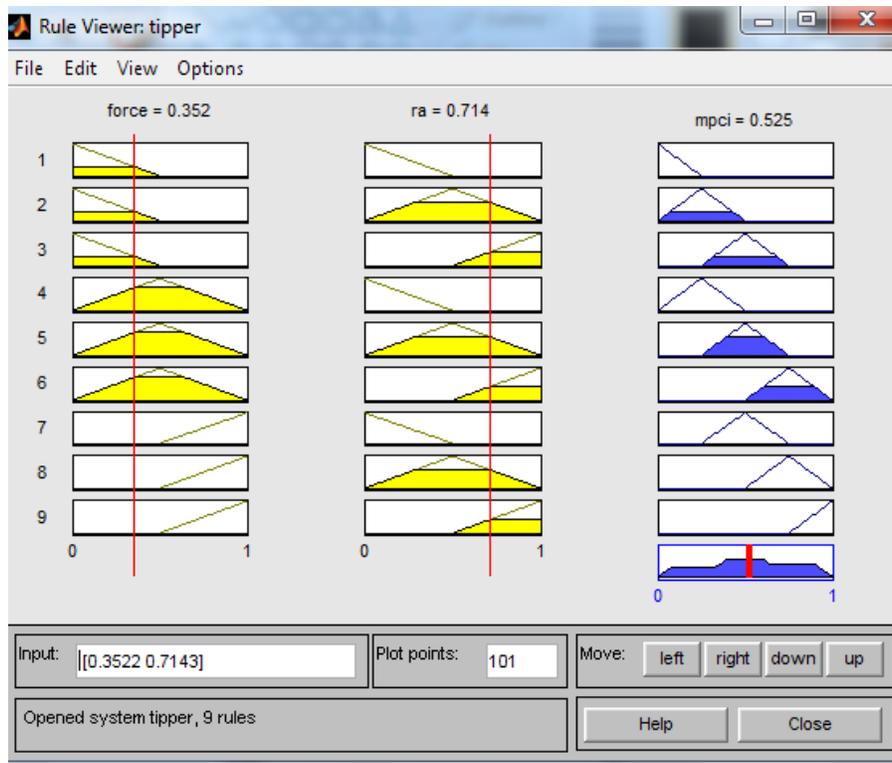


Figure 4.4 Computation of MPCl

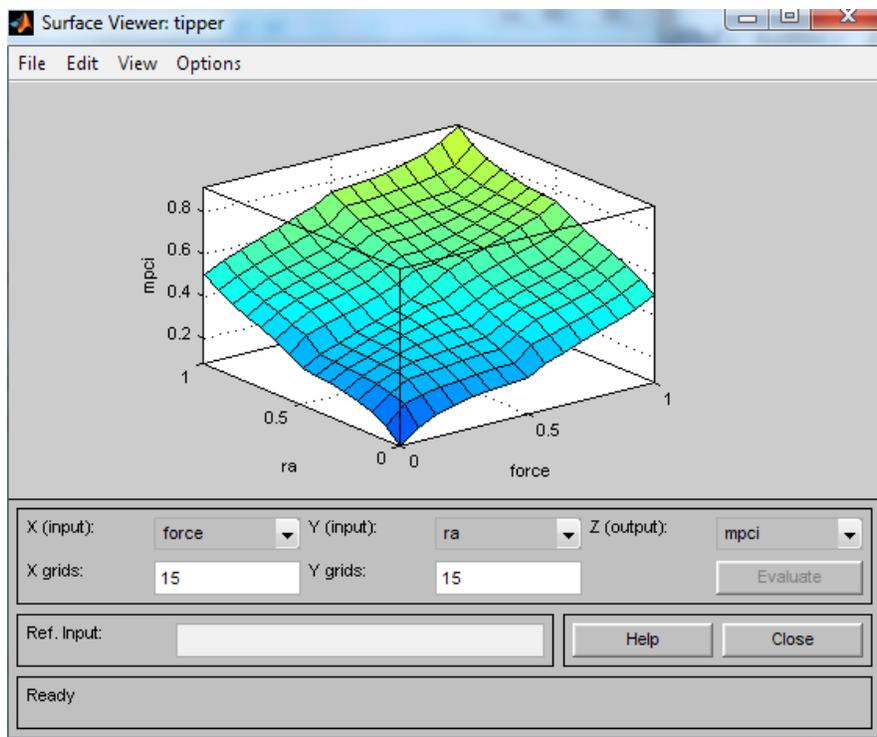


Figure 4.5 Fuzzy inference surface plot

Sl. No.	Factorial Settings					MPCI	S/N Ratio of MPCI (dB)	
	A	B	C	D	Experiments		Predicted at Optimal setting	
1	1	1	1	1	0.895	-0.9635	2.3809	
2	1	2	2	2	0.649	-3.7551		
3	1	3	3	3	0.181	-14.8464		
4	2	1	2	3	0.758	-2.4066		
5	2	2	3	1	0.21	-13.5556		
6	2	3	1	2	0.706	-3.0239		
7	3	1	3	2	0.396	-8.0461		
8	3	2	1	3	0.873	-1.1797		
9	3	3	2	1	0.525	-5.5968		

Table 4.7 Computed MPCI values and corresponding S/N ratios

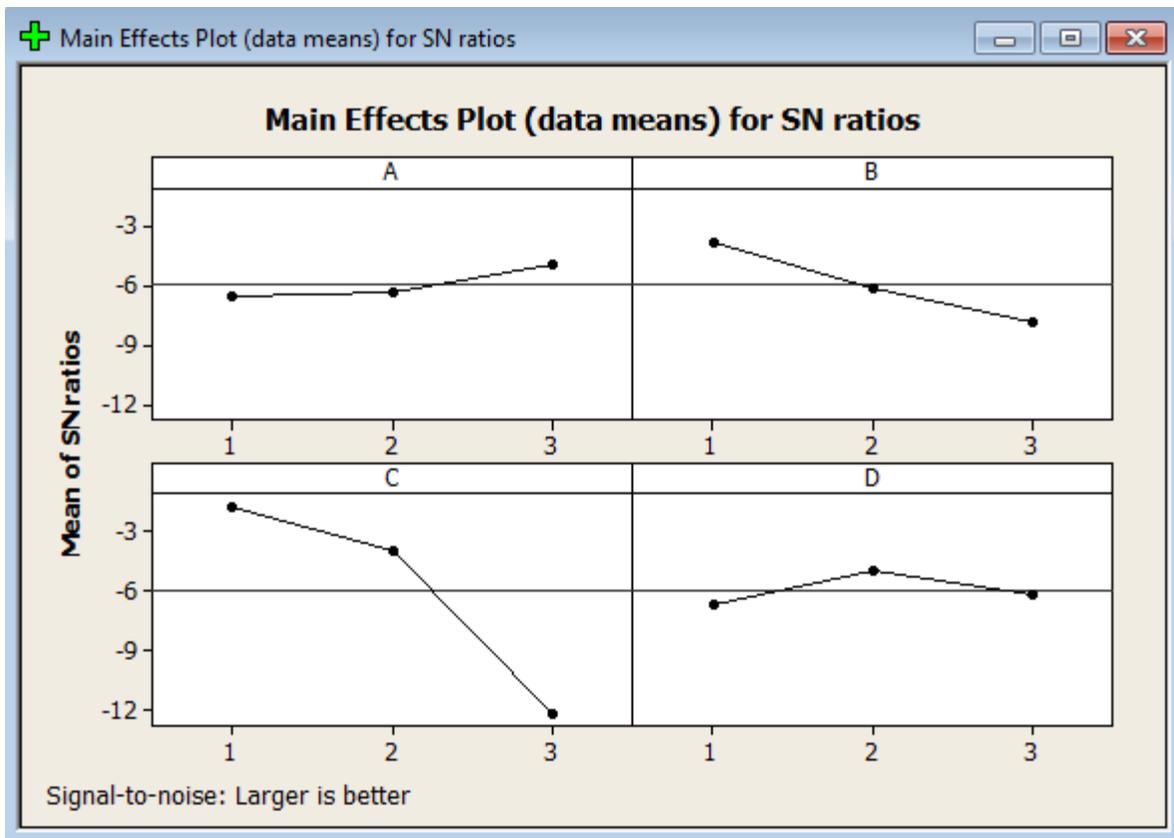


Figure 4.6 S/N ratio plot for MPCI (Evaluation of optimal setting) A3 B1 C1 D2

Level	A	B	C	D
1	-6.522	-3.085	-1.722	-6.705
2	-6.329	-6.163	-3.92	-4.942
3	-4.941	-7.822	-12.149	-6.144
Delta	1.581	4.017	10.427	1.764
rank	4	2	1	3

Table 4.8 Response table for S/N ratios of MPCl

## CHAPTER 5

### 5. Conclusions

**5.1.** The subsequent conclusions can be derived from the experiments and study that were done on the aluminium 6061 workpiece with the carbide insert tool.

1. Taguchi method can be efficiently used in off-line quality control in which the experimental design is combined with the quality loss.
2. Most important parameters are found using Taguchi experimental design and fuzzy logic where two responses  $R_a$  and peak force are combined together to one.
3. From the analysis it reveals that feed rate and depth of cut are the two factors affecting more the force and surface quality. Principal cutting edge angle and depth of cut are not significant factors.

A confirmatory test has been carried out after getting the optimal settings A3 B1 C1 D2 and the value of surface roughness was found to be 1.145279 kgf and surface roughness  $R_a$  1.1 $\mu$ m.

## **5.2. Future possibilities**

The work used parameters speed of cut, depth of cut, principal cutting edge angle and feed rate find the optimum condition for better surface finish and reduced forces. Apart from these variables other variable like cutting fluids, tool material , machine or spindle power, rigidity of machine, can be used and their influence on various output results can be studied.

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