Multi Objective Optimization of Cutting Parameters in Turning Operation to Reduce Surface Roughness and Tool Vibration

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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 Tool Vibration"***submitted by ***Sri Sudhir Kumar Dash*** 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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Sudhir Kumar Dash

Abstract

Optimization of Multi response is now-a-days mostly used optimization technique which is better than single response optimizing technique because all the output is affected at a time by all the input factors .The objective of this project work is to determine the optimal setting of cutting parameters (speed(N)m/min , depth of cut(d) mm , feed(f)mm/rev) and variation in principal cutting edge angle (Φ) of the tool to have a reduced tool vibration (in terms of peak acceleration) and surface roughness(Ra) . In this work the experiment has been carried out in lathe dry turning (without using cutting fluid) of a commercially available 6061 grade aluminum as a work material and carbide insert tool (SCMT 09T308-TN5120). The ranges of process 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 principal cutting edge angle (74,71,68 degree). This study highlights applications of Fuzzy logic and use of Taguchi experiment design to optimize the multi response parameters on turning operation. For this experiment Taguchi design of experiment was carried out to collect the data for surface roughness and tool vibration. The results indicate the optimum values of the input factors and the results are conformed by a confirmatory test.

Contents

Item **Page No**

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

List of Tables

Tables **page**

List of figures

CHAPTER 1

1. INTRODUCTION AND STATE OF ART

The challenge of modern machining industries is mainly focused on the achievements of high quality in terms of work piece dimensional accuracy ,surface finish, high production rate, less wear on the cutting tool ,economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact[1]. Surface roughness plays an important role in many areas and is factor of great importance in evaluation of machining accuracy [2]. Turning is the process whereby a single point cutting tool removes unwanted material from the cylindrical work piece and the tool is fed parallel to the axis of rotation. It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not. In turning operation vibration is a frequent problem .Vibration in machine tool is directly affecting the surface finish of the work material in turning process. So vibration of a machine tool is one of the major factors limiting its performance. The vibration occurring in the machine tool is due to the dynamic nature of force acting during the turning operation on the cutting tool [3]. Vibration can be measured in terms of peak acceleration, r.m.s value of velocity, peak to peak displacement.

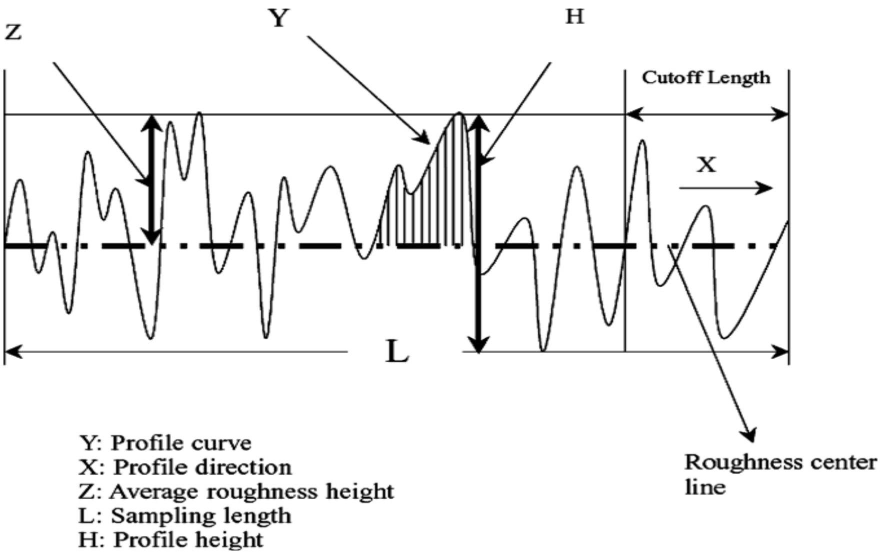


Figure 1.1 Surface roughness profile. Reference [4]

The average surface roughness is given by [5]

$$Ra = \frac{1}{L}\int_0^L |y(x)|dx \quad , \qquad \ldots\ldots\ldots\ldots (1)$$

Where Ra is the arithmetic average deviation from mean line, L is the sampling length and Y the ordinate of the profile curve.

Ghani et al. [6] presented a study of tool life, surface finish and vibration, while turning nodular cast iron using ceramic tool. They found that surface finish was to be almost constant with the progression of the flank wear under different cutting conditions. They also observed that as the speed increases, the vibration during cutting decreases and at low depth of cut, the vibration remains almost constant with the increase of flank wear.

Diniz et al. [7] presented a study on correlating tool wear, tool life, surface roughness and tool vibration in finish turning with coated carbide tools. The work piece machined was AISI 4340 steel and tool coated with carbide insert. Two accelerometer are attached to the tool to measure the vibration and r.m.s signal was used to correlate with the surface roughness. They concluded that the feed didn’t influence the vibrational signal and had a little effect on surface roughness. The surface roughness value decreases slightly after a short cutting time due to chamfering of the edge radius.

Hasan et al.(2006)[1] studied to analyze the optimum cutting parameters to minimize the roughness in turning SCM 440 alloy steel by Taguchi method. Experiment was designed using Taguchi method and 18 experiments were designed and they found that depth of cut has the significant effect on producing lower surface roughness followed by feed. Speed has not so remarkable effect on it. In this experiment effect of vibration and tool chattering factors are being neglected for analysis.

Thomas M. et al. [8] studied the effect of tool vibration on surface roughness during lathe dry turning process on mild carbon steel samples at different levels of speed, feed, depth of cut, tool nose radius, tool length and workpiece length. Roughness was measured in Motutoya SurfTest 201 apparatus and for vibration triaxial accelerometer is being used. Vibration analysis shows that the dynamic force, related to the chip thickness variation acting on the tool, is related to the amplitude of tool vibration at resonance and to the variation of tools natural frequency while cutting. The analogy of effect of cutting parameters between tool dynamic force and surface roughness was studied. After the analysis of variance it is shown that there exist a relation between surface roughness and tool dynamic force when operating in a built up edge range.

Kassab and Khoshnaw(2007)[9] studied the effect of cutting tool vibration on surface roughness of work piece in dry turning operation .The work piece used was cold drawn-medium carbon steel bars shape and the vibration measuring instrument used is a Hottinger SM which measures amplitude and velocity of a point on cutting tool. Their experiment reveals that the cutting tool acceleration has a significant effect on surface roughness of workpiece. The surface roughness of the workpiece is proportional to cutting tool acceleration. This effect interact with other independent variable such feed rate, depth of cut, speed. Surface roughness of workpiece increases parallel to the tool vibration with increasing tool over hang.

Dogra and Sharma et al. [10] presented a research on effect of tool geometry variation i.e. tool nose radius, rake angle, groove on the rake face, variable edge geometry, wiper geometry, curvilinear edge tools and their effect on tool wear ,surface roughness and surface integrity of the machined surface. They concluded some important points like during finish hard turning increase in the rake angle or the chamfer angle as well as the hone cutting edge radius allowed an increase in the compressive residual stress in the subsurface. Further the increased radius of a cutting tool will produce larger compressive residual stress beneath the machined surface**.** Increasing the nose radius has a direct effect on cutting forces which leads to a significant increase in the ploughing effect in the cutting zone.

Gaitonde et al.[11] used the technique artificial neural network (ANN) method and using this surface roughness model is being developed to investigate the cutting conditions during turning of steel, 9SMnPb28k (DIN). The experiment was designed as L27 orthogonal array with three levels for each factor in order to define the knowledge base for ANN training using error back propagation training algorithm (EBPTA). Three-Dimensional surface plots are generated considering two parameters at a time and other is kept a level 2, to determine the turning effect on Ra and Rt .They concluded from their experiment that the surface roughness is highly sensitive to feed and speed while depth of cut has less effect on it. They also concluded that ANN can detect any value of non linearity that exists between the process response and the input parameters and exhibits good generalization.

Nalbant et al.[4] described an application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. TiN coated tool and AISI 1030 steel is used as workpiece and the experiment was carried in John-Ford T35 CNC lathe machine. The experiment was designed using Taguchi method of experiment design and L9 orthogonal array was drawn and accordingly readings are taken. Three parameters insert radius, feed rate and depth of cut are being optimized. The result of the experiment suggests that the insert radius and feed rate are the main controllable parameters which affect surface roughness more in turning AISI 1030 carbon steel. Instead of engineering judgment surface roughness can be improved by this approach.

1.1 Objective of present work

Many literatures are being studied on single response optimization but multi-response optimization is a better approach for engineering side of views. Present study highlights application feasibility of fuzzy logic in Taguchi’s optimization philosophy to optimize multi responses (cutting parameters and principal cutting edge angle) in turning operation to reduce vibration and surface roughness.

2. METHODOLOGY

2.1 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 and d) defuzzification interface. Detail analysis of fuzzy can be found in numerous literatures [Zadeh (1965, 1976); Mendel (1995); Cox (1992)].

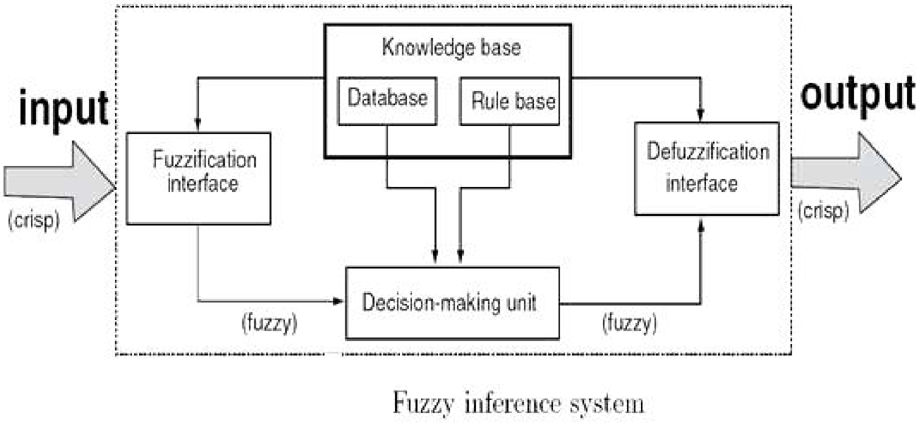


Figure 2.1

[12]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.

2.2 Taguchi method

[13] Taguchi methods are statistical methods developed to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising.

Taguchi's work 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 was mostly used for engineering optimization processes. It should be carried in three step approach i.e. system design, parameter design, tolerance design. In system design, scientific and engineering principles and experience are used to create a prototype of the product that will meet functional requirements. Parameter design is to optimize the settings of process parameter values for improving performance characteristics. And in tolerance design, tolerances are set around the target a value of the control parameter identified in the parameter design phase and is done only when the performance variation achieved by the settings identified in the parameter design stage is not acceptable. [4]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: $S/N_T = 10 \log (\frac{\bar{y}}{s^2})$ …………….. (2)

Larger is the better (maximize): $S/N_L = -10\log \frac{1}{y} \sum_{i=1}^{n} \frac{1}{yi^2}$ …………….. (3)

Smaller is better (minimize): $S/N_S = -10\log \frac{1}{y} \sum_{i=1}^{n} yi^2$ ……………. (4)

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

3. EXPERIMENTATION

3.1 TOOLS AND EQUIPMENTS USED

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

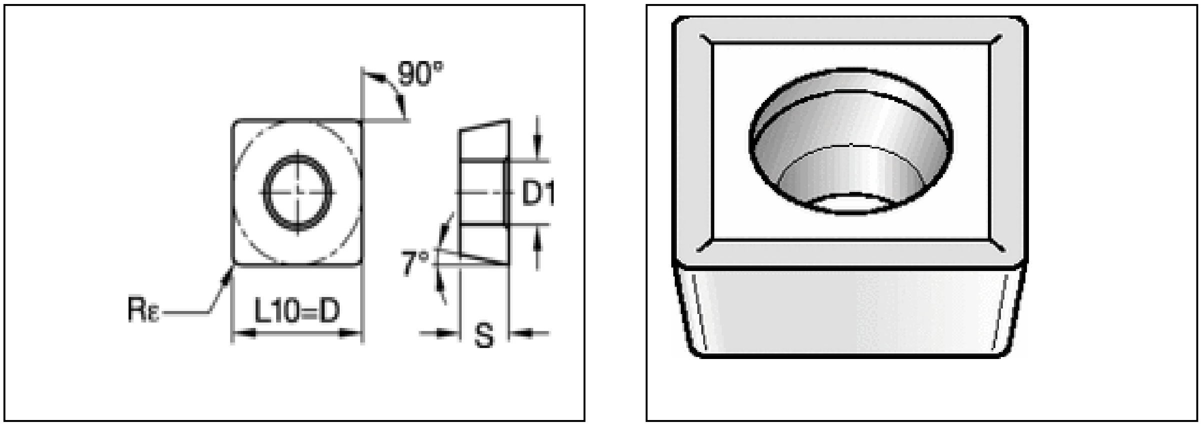


Figure 3.1 Carbide insert tool [14]

Table 3.1 Specification of cutting tool

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

3.1.2 WORKPIECE The selected work piece material for this experiment is commercially available 6061 grade Aluminium**.** The composition of the 6061 Aluminium work piece is:

Table 3.2 Chemical Composition [15]

Aluminium	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Ti**	**Zn**	**Cr**
6061 (% by weight)	95.85-98.56	0.4-0.8	0.7	0.15-0.4	0.15	0.8-1.2	0.15	0.25	0.04-0.35

3.1.3 VIBROMETER

TV300 vibration tester [16], TV300 is made up off a piezoelectric acceleration transducer which converts the vibrational signal to the electric signal. It is very accurate and has got very wide measuring range. It analyses the input signal and can measure peak acceleration, velocity, displacement, rotation speed and natural frequency. It measures acceleration in peak, velocity in r.m.s and displacement in peak to peak at the same time. It measures peak acceleration (0.1 – 392 m/s2), rms velocity (0.01 – 80 cm/s), peak to peak displacement (0.001 – 10 mm). It can show spectrum and charts.

Figure 3.2 Experimental setup

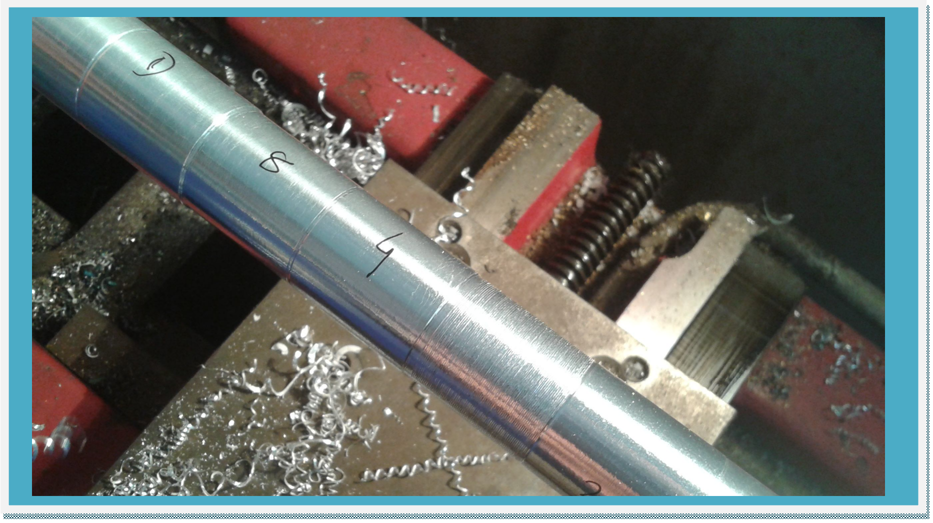


Figure 3.3 Machined workpiece

The process parameters and their ranges considered based on the idea of literature review and experience of some preliminary experiments shown in **Table 4.1.** The design of experiment according to Taguchi method and collected data are in **Table 4.2.**

3.2 Working procedure

First the working of vibrometer was checked taking some runs on Aluminum(D=27mm). Then according to the experiment designed the cutting parameters and principal cutting edge angle are adjusted in the lathe machine. The work piece was given initial roughing pass. Nine equal parts of 30 mm are marked equally on the work piece. So taking the different parameters and changing principal cutting edge angle readings are taken for analysis. Using the TV300 vibrometer the vibration of the cutting tool was measured in the form of the peak acceleration of the cutting tool. Each part is being marked as numbers for taking the surface roughness value .The surface roughness was measured by Talysurf (Taylor Hobson, Surtronic 3+).

4. Data Analysis: Application of Taguchi method & FIS

The peak acceleration data and surface roughness data was collected according to the Taguchi analysis method of the Minitab 14 software. [17] Minitab 14$^{®}$ software was used as it provides an effortless method to create, edit and update graphs. Also it provides a dynamic link between a graph and its worksheet that helps in updating the graph automatically whenever the data is changed. Its appearance and easy to use enhancements further add to its advantages.

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

1. Computation of (Signal-to-Noise Ratio) S/N ratio of experimental data **(Table 4.3)** has been done. For calculating S/N ratio of Ra and Vibration a Lower-the-Better (LB) criterion has been selected.
2. S/N ratios have been normalized based on Higher-the-Better (HB) criterion **(Table 4.4)**.
3. 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 4.5)** 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.

4. The crisp values of MPCI **(Table 4.2)** have been optimized by using Taguchi' philosophy. The predicted optimal setting has been evaluated from *Mean Response Plot* of MPCIs and it became A1 B2 C1 D3.
5. Optimal setting has been verified by confirmatory test.

Table 4.1 Domain of experiments

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	Φ(degree)	D	74	71	68

Table 4.2 Design of experiment and collected data

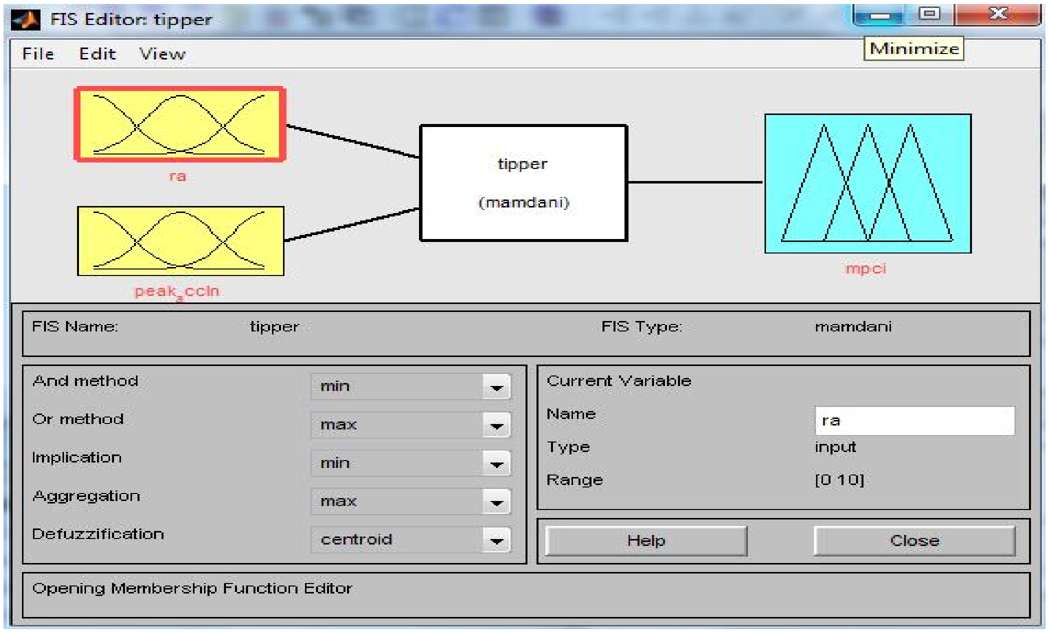
Factorial settings (Coded)				Experimental data		MPCI Crisp Values
A	B	C	D	Vibration(peak accel.)(m/s2)	R_a (µm)	
1	1	1	1	3.48	1.2	0.750
1	2	2	2	6.57	3.6	0.612
1	3	3	3	6.11	8.2	0.465
2	1	2	3	5.82	2.0	0.660
2	2	3	1	8.18	9.4	0.295
2	3	1	2	6.46	2.0	0.670
3	1	3	2	13.9	7.8	0.243
3	2	1	3	7.93	1.0	0.750
3	3	2	1	14.43	3.4	0.361

Table 4.3 Computation of S/N ratios

Sl. No.	S/N ratio for peak accel.(dB)	S/N ratio for R_a (dB)
1	-10.8316	-1.5836
2	-16.3513	-11.1261
3	-15.7208	-18.2763
4	-15.2985	-6.0206
5	-18.2551	-19.4626
6	-16.2047	-6.0206
7	-22.8603	-17.8419
8	-17.9855	0.000
9	-23.1853	-10.6296

Table 4.4 Normalized of S/N ratios

Sl. No.	Normalized S/N ratio of peak accel.	Normalized S/N ratio of R_a
1	1	0.918633
2	0.553194	0.428334
3	0.604231	0.060952
4	0.638416	0.690657
5	0.399086	0
6	0.565061	0.690657
7	0.026307	0.083272
8	0.420910	1
9	0	0.453844



FIS Name: tipper

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

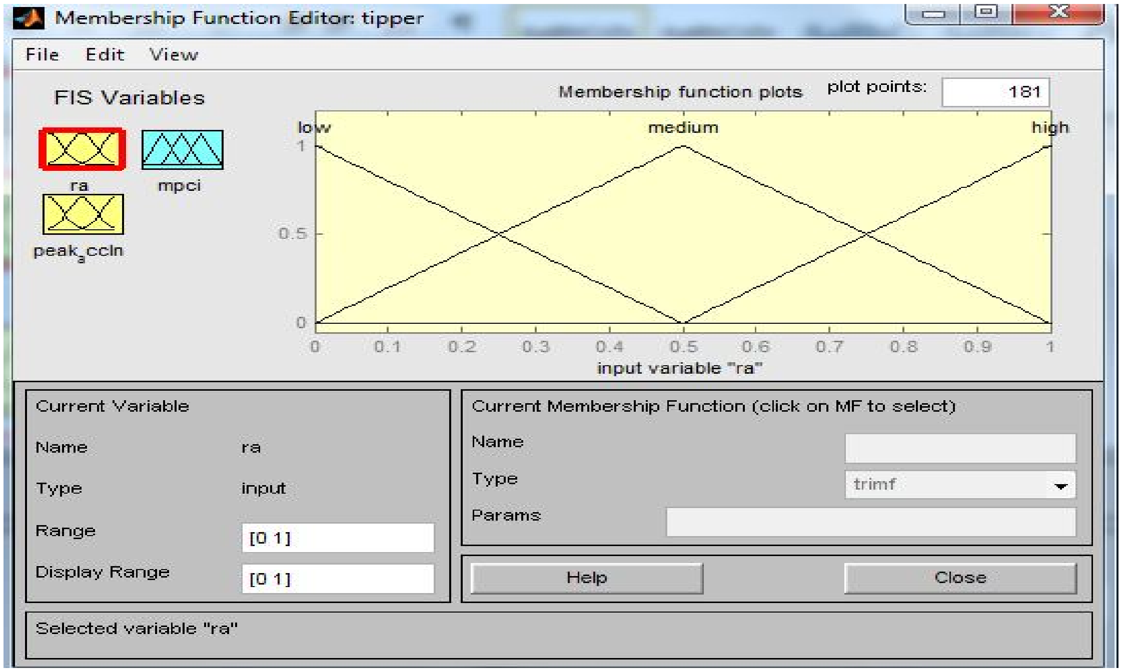
Name: ra

Type: input

Range: [0 10]

Opening Membership Function Editor

Figure4.1 Fuzzy inference tipper



plot points: 181

Name ra

Type input

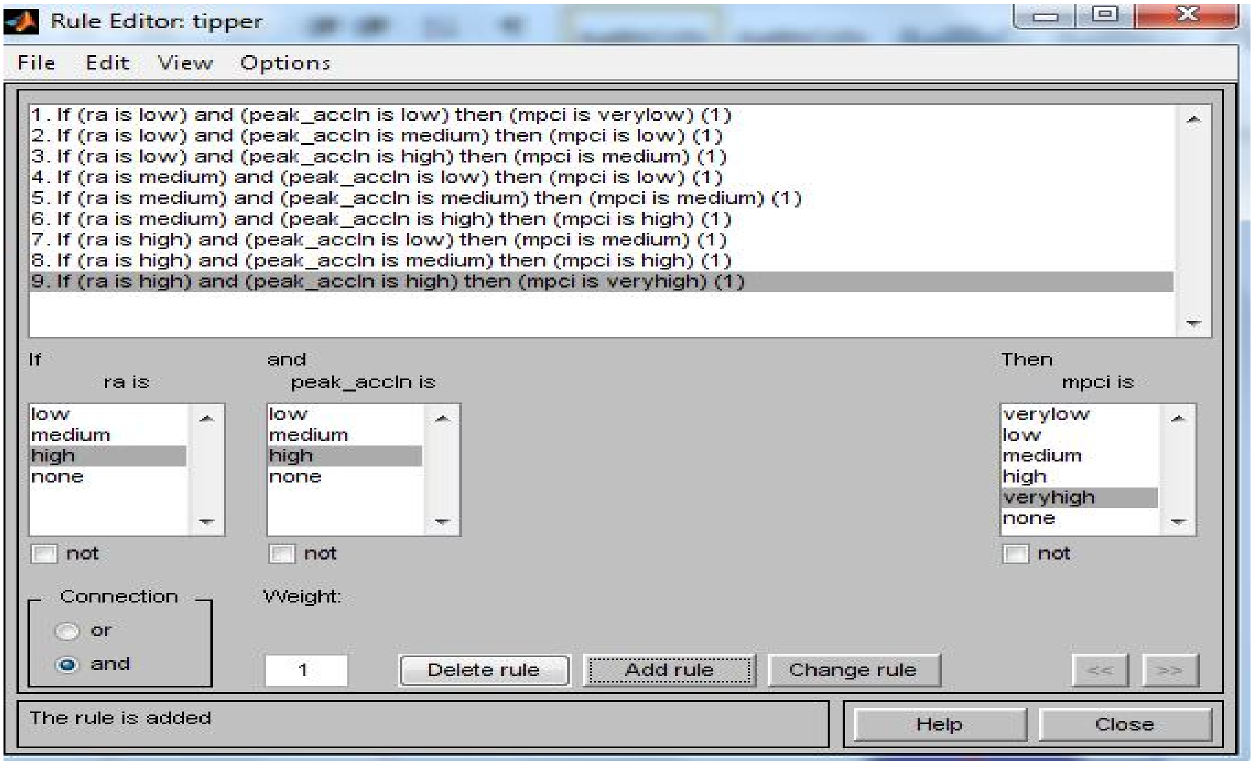
Range [0 1]

Display Range [0 1]

Type trimf

Selected variable "ra"

Figure4.2 Membership function



1. If (ra is low) and (peak_accln is low) then (mpci is verylow) (1)
2. If (ra is low) and (peak_accln is medium) then (mpci is low) (1)
3. If (ra is low) and (peak_accln is high) then (mpci is medium) (1)
4. If (ra is medium) and (peak_accln is low) then (mpci is low) (1)
5. If (ra is medium) and (peak_accln is medium) then (mpci is medium) (1)
6. If (ra is medium) and (peak_accln is high) then (mpci is high) (1)
7. If (ra is high) and (peak_accln is low) then (mpci is medium) (1)
8. If (ra is high) and (peak_accln is medium) then (mpci is high) (1)
9. If (ra is high) and (peak_accln is high) then (mpci is veryhigh) (1)

ra is: high

peak_accln is: high

mpci is: veryhigh

Connection: ● and

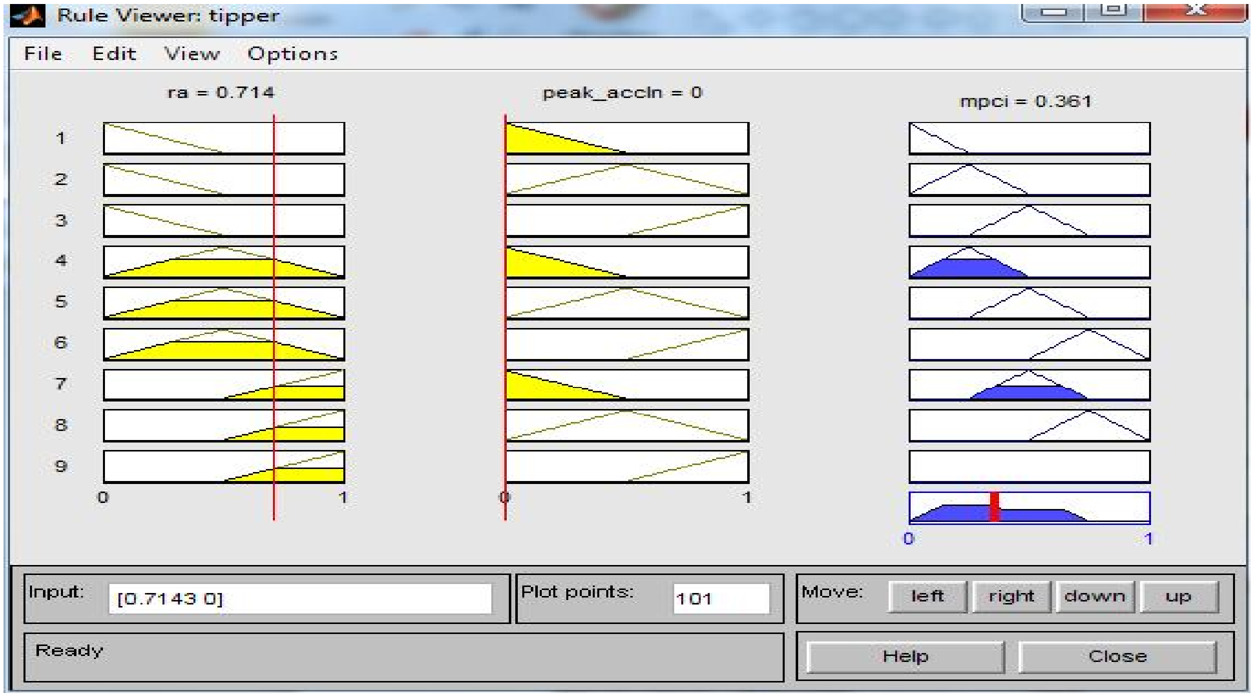
Weight: 1

The rule is added

Figure4.3 Fuzzy rule viewer

Table 4.5 Fuzzy rule matrix

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


Rule Viewer: tipper

ra = 0.714

peak_accln = 0

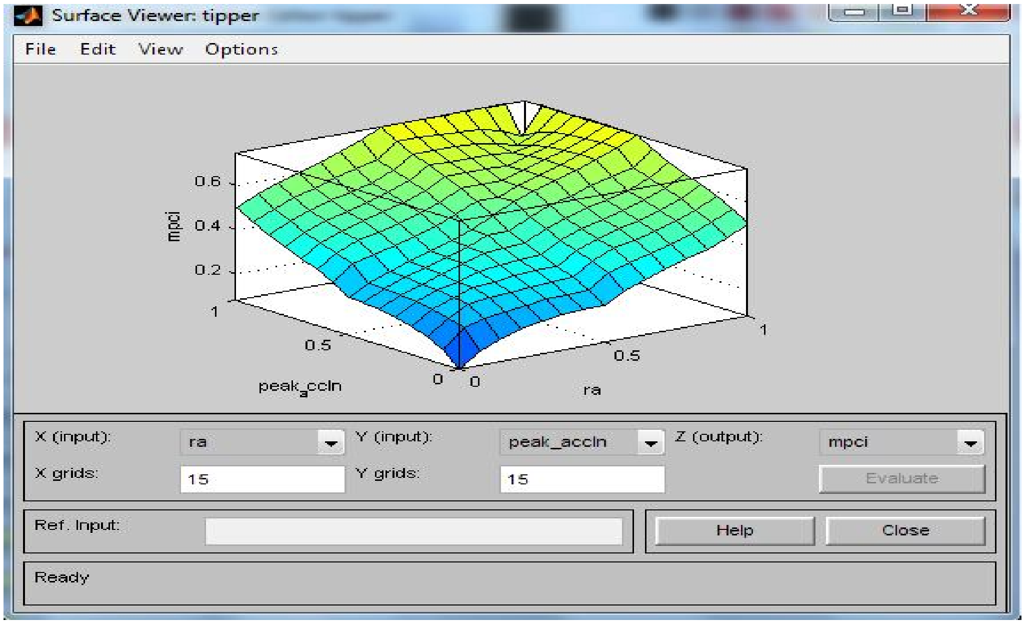
mpci = 0.361

Input: [0.7143 0]

Plot points: 101

Ready

Figure4.4 Computation of MPCI



X (input): ra
Y (input): peak_accln
Z (output): mpci
X grids: 15
Y grids: 15
Ref. Input:
Ready

Figure4.5 Fuzzy inference surface plot

Table 4.6 Computed MPCI values and corresponding S/N ratios

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	0.750	-2.4988	0.908498
2	1	2	2	2	0.612	-4.2650	
3	1	3	3	3	0.465	-6.6509	
4	2	1	2	3	0.660	-3.6091	
5	2	2	3	1	0.295	-10.6036	
6	2	3	1	2	0.670	-3.4785	
7	3	1	3	2	0.243	-12.2879	
8	3	2	1	3	0.750	-2.4988	
9	3	3	2	1	0.361	-8.8499	

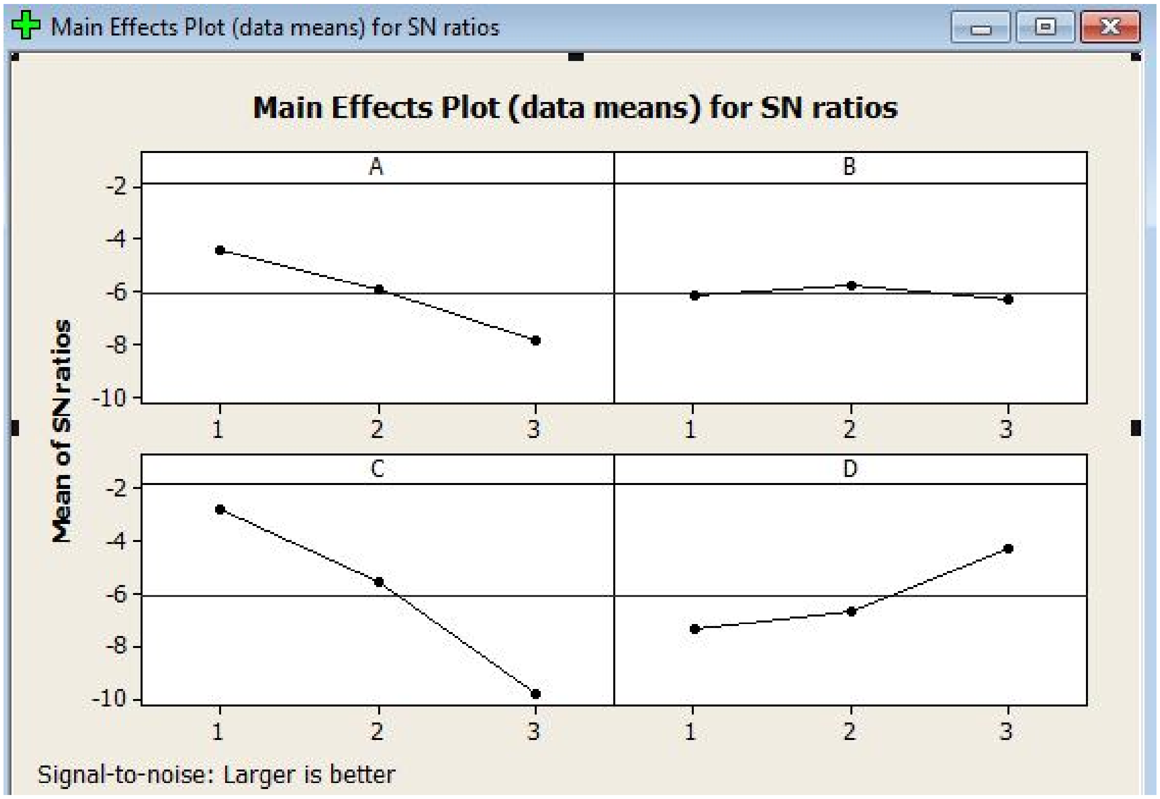


Figure 4.6 S/N ratio plot for MPCI (Evaluation of optimal setting) **A1 B2 C1 D3**

Table 4.7 Response table for S/N ratios of MPCI

Level	A	B	C	D
1	-4.472	-6.132	-2.825	-7.317
2	-5.897	-5.789	-5.575	-6.677
3	-7.879	-6.326	-9.847	-4.253
Delta	3.407	0.537	7.022	3.064
rank	2	4	1	3

5. Conclusions and Recommendation

5.1 Conclusions

The following conclusions can be made after the experiment and analysis were done on the aluminum 6061 workpiece with the carbide insert tool.

1. Taguchi method can be efficiently used in off-line quality control in that the experimental design is combined with the quality loss.
2. From the analysis it reveals that feed rate and cutting speed are the main factors affecting more the surface roughness and vibration. Principal cutting edge angle and depth of cut are the least affecting factors.

A confirmatory test has been carried out after getting the optimal settings A1B2C1D3 and the value of surface roughness was found to be 3.4 µm and peak acceleration 6.26 m/s^2.

5.2 Recommendations

A lot of research work has been carried out on optimizing cutting parameters and tool geometry. Further study can be possible considering more factors (tool nose radius, use of cutting fluid, material hardness) in the research to see how the factors affecting the vibration and surface roughness. Artificial Neural Networking method (ANN), Regression analysis method can also be used to get the optimum data and to compare the data with Fuzzy logic method to get the best results.

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