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

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In

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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 Cutting forces and Tool Vibration**”* submitted by ***Sri Raj Amrit Mohapatra*** 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.

ROURKELA
DATE

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Raj Amrit Mohapatra

ABSTRACT

These days one of the most important machining process in industries is turning. Turning is affected by many factors such as the cutting velocity, feed rate, depth of cut and geometry of cutting tool etc., which are input parameters in this project work. The desired product of dimensional accuracy and less surface roughness is influenced by cutting force and tool vibration which are the responses and the functions of these input parameters.

In this project work we determine the optimal setting of cutting parameters cutting speed (N) , depth of cut(d) , feed(f) and principal cutting edge angle (Φ) of the tool to get a minimum cutting force and tool vibration. In this project dry turning SS304 of diameter 30mm as a work piece and carbide insert tool (SCMT 09T308-TN5120) is done in an automatic lathe. The range of cutting parameters are cutting speed(13.18, 20.724,33.912m/min) ,feed rate(0.105,0.16,0.25 mm/rev), depth of cut(0.5,0.6,0.7mm) and the angle (78,66,62 degree).

This study highlights the use of Grey logic and use of Taguchi design to optimize the multi response in turning operation. For this purpose Taguchi design of experiment was carried out to collect the data for tool vibration and cutting forces. The result shows the optimum values of the input parameters and a confirmatory test is held to confirm the results.

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CHAPTER 1

1.1.INTRODUCTION AND LITERATURE REVIEW

In the modern industry technology is advancing. For that engineers should be ready to achieve product of good surface finish, economic production, less wear of cutting tool with optimizing the use of resources [1]. One of the most important manufacturing process in mechanical engineering is metal cutting which is defined as metal removal of chips from job to achieve the desired product of appropriate shape, size and surface roughness [2]. In metal cutting most regularly used method is turning in which a single point cutting tool does metal removal by giving feed in a parallel direction to the axis of rotation. Turning can be done in an automated lathe machine which does not require more labor or frequent supervision by operator.

Tool vibration plays an important role in turning. A large number of extensive study has been conducted in the past on tool vibration control [3,4,5]. Vibration in a turning is of 3 types [4]. Free vibration has little insignificance as compared to other 2 types. Self excited vibration is produced from instability in turning. Vibration in a machine is direct effect of dynamic nature of force in turning process which is called forced vibration [6]. It is needed to be reduced because an uncontrolled vibration brings wear in cutting tool, decreases the surface finish and also produces unhealthy noise. Tool vibration analysis [11] has revealed that cutting parameters not only have an effect on the amplitude of vibration, but also on the variation of the natural frequency of the tool. Vibration can be measured in terms of peak to acceleration, r.m.s of velocity and peak to peak displacement. Here in this project work peak to peak displacement is taken into consideration for measuring vibration

In addition to vibration cutting forces also affects the deformation of work piece, dimensional accuracy and chip formation. So it is also an important response in metal machining [7].

Our main concern now a day is to achieve improved quality and economic productivity with reduced cost and time. It is challenging to acquire good surface finish and less tool wear while working with materials having high strength, corrosive resistance and wear resistance in turning. In order to overcome the above problem, optimized cutting parameters are to be employed [8].So optimization of multi response is very much essential in industrial application. As compared to single response optimizing technique it is better because all factor is affected at a time by all the input factors. For this drive Taguchi method is introduced which is an important statistical tool that provides cost effective and systematic way to optimize cutting parameters. It has been successfully used in designing good quality at low cost in the field of automotive, aerospace etc. [9]. The theory of grey system is an advanced procedure for performing prediction, relational analysis, and decision making in many areas which is used for finding optimal solution in this project work [14].

Younis K. Khoshnaw and Safeen Y. Kassab* [10] presented a study in the consequence of cutting tool vibration on surface roughness of work piece in dry turning. The work piece used was cold drawn-medium carbon steel bars shape. The vibration measuring instrument used is a Hottinger SM which measures amplitude and velocity of a point on cutting tool. The study concludes that the cutting tool vibration has a significant effect on surface roughness of work piece. The surface roughness of the job is proportional to cutting tool acceleration. This effect interrelate with other parameters such feed rate, depth of cut, speed. Surface roughness of work piece upsurges parallel to the tool vibration with increasing tool over hang.

Thomas M., Beauchamp Y. [3] analyzed the effect of tool vibration on surface roughness. Work piece taken was mild carbon steel. Dry turning is done in lathe with different input parameters feed, speed, depth of cut, tool noise radius, tool length, job length. A full factorial experimental design results in the best surface roughness is achieved at low feed rate, large nose radius and high cutting speed. It also concludes that depth of cut has no significant effect on surface roughness, apart from when operating inside the built up edge range. The effect of built up edge formation on surface roughness can be minimized by increasing depth of cut.

M.S.Selvam [11] studied the frequency of tool vibration and surface profile in turning. Work piece taken was plain carbon steel rod and tool taken was H.S.S tool. The major frequencies of tool vibration and the surface profile in the circumferential direction were found to be the same. The cutting speed and work piece rigidity were found to impact the surface roughness. Comparison of tool vibration during idle running and cutting shows that the lower frequencies of tool vibration are due to the machine tool and the higher frequencies above 500 Hz are due to the machining that is the mechanism of chip removal and built-up-edge fracture.

O.B. Abouelatta [12] studied the correlation between surface roughness and cutting vibration in turning and derived the mathematical model for the predicted roughness parameters based on cutting parameters and cutting tool vibration. Work piece taken was free cutting steel and tool used was SV 18 universal machine tool. An FFT analyzer was used to measure tool vibration and surtronic 3 was used to measure the surface roughness. It concludes that the predicted models depend on both cutting parameters and tool vibration are more accurate than those only depend upon cutting parameters.

S. Rangnathan [13] visualizes the multi-response optimization of machining parameters in hot turning of stainless steel (type 316) based on Taguchi technique. The workpiece heated with liquid petroleum gas flame burned with oxygen was machined under different parameters. Tool used was WC insert. From the grey analysis, a grey relational grade is acquired and grounded on this value an optimum level of cutting parameters has been found. Furthermore, using analysis of variance method, significant contributions of process parameters have been determined. The study shows that a cutting speed at 113.1 m/min, feed rate at 0.381 mm/rev, and workpiece temperature at 400°C will give the optimum results for hot turning of stainless steel (type 316) by employing multi-response optimization using grey relational analysis. Experimental results disclose that feed rate and cutting speed are the leading variables on multiple performance analysis and can be further enhanced by the hot turning process.

L. B. Abhang & M. Hameedullah [14] used grey relational analysis for optimizing the turning process parameters for the workpiece. Here surface roughness and the chip thickness were the responses. The workpiece material used for experimentation was EN-31 steel (size 500 mm in length and 51 mm in diameter). The cutting tools used for experimentation were CNMA 120404, CNMA 120408, CNMA 120412 and diamond-shaped carbide. A factorial design with eight added center points was used for the experimental design. The minimum surface roughness and smallest chip thickness are 9.83 and 0.32 mm, respectively, obtained at optimal conditions of cutting speed, 1,200 rpm; feed rate, 0.06 mm/rev; nose radius, 0.8 mm; and less concentration of solid–liquid lubricant(10% boric acid + SAE-40 base oil).

Ilhan Asilturk, Harun Akkus [15] used the L9 orthogonal array in a CNC turning machine. Dry turning tests are done. Work piece used was hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Each experiment is repeated three times and each test uses a new cutting insert to ensure accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are implemented to explore effects of cutting speed, feed rate and depth of cut on surface roughness. The number of experiments in the same area in hard turning operations was reduced by using the Taguchi experimental design to determine optimum cutting conditions. Results show that the feed rate has the most significant effect on Ra. In addition to it the effects of two feed rate-cutting speed and depth of cut-cutting speed are also important.

Ahilan, c. [16] studied multi response optimization of CNC turning parameters with help of grey based Taguchi method. L_{27} orthogonal array is used. Work material taken was AISI 304 stainless steel and carbide insert tool was used as tool material. Power consumption and surface roughness were the outcomes. Taguchi's signal-to-noise ratios were evaluated based upon their performance characteristics. A grey relation grade is obtained from s/n ratio based upon which optimal level of input parameters were determined. This analysis concluded that cutting speed influences more followed by feed rate followed by depth cut followed by nose radius.

Raju Shrihari Pawade & Suhas S. Joshi [17] analyzed Multi-objective optimization of surface roughness and cutting forces. Work piece used was Inconel 718. A commercially available low Cubic Boride Nitride (CBN) content inserts were used as tool. Study approach combined the Taguchi design of experiments with grey relational analysis. Grey relational theory is introduced to decide the optimal process parameters that give lower magnitude of cutting forces as well as surface roughness which are the responses. Results showed that depth of cut had statistical significance on overall turning performance. It concluded that an increase in the value of predicted weighted GRG from 0.1660 to 0.2071 confirms the improvement in the performance of high-speed turning process using optimal values of process parameters.

1.2. Objective of present work

Many studies are carried out on single response optimization. From engineering point of view multi objective optimization is better as compared to single response optimization. So the present work shows the application of grey relation combined with Taguchi's optimization design to find optimal setting of the input parameters (feed, speed, depth of cut and principal cutting edge angle) to minimize cutting forces and tool vibration (in terms of peak to peak displacement).

CHAPTER 2

2. Brief description of apparatus used

2.1. Cutting tool specification

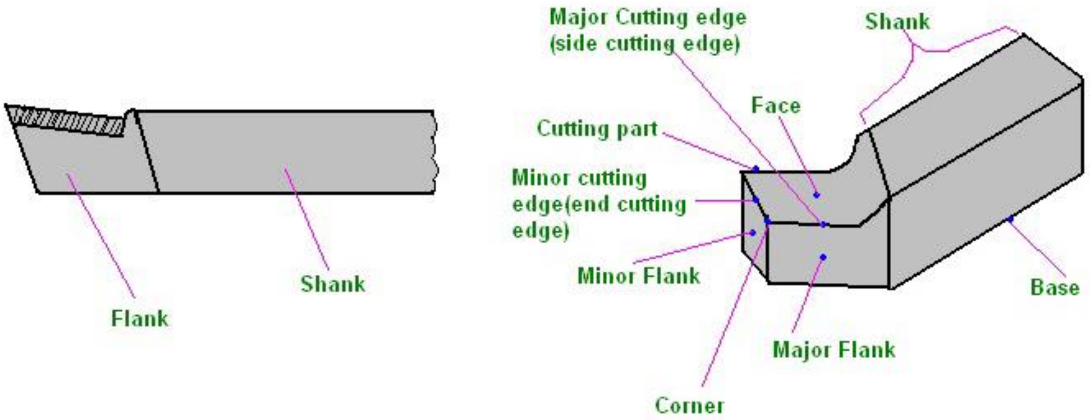


Figure 2.1 Nomenclature of single point cutting tool [18]

Tool life decreases with improper edge formation. So edge preparation has an important effect on tool life. The principal-cutting edge, which performs the primary work during turning, is formed by the intersection of the rake and the side flank surfaces. The intersection of the side relief and end relief surfaces produce the end cutting edge. The point at which the side and end-cutting edges converge is called the tool nose. It is the scrawniest part of the tool and determines 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).

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

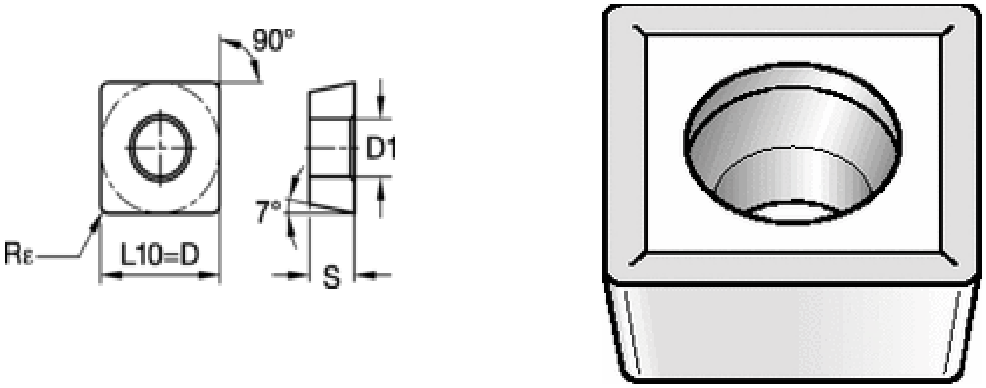
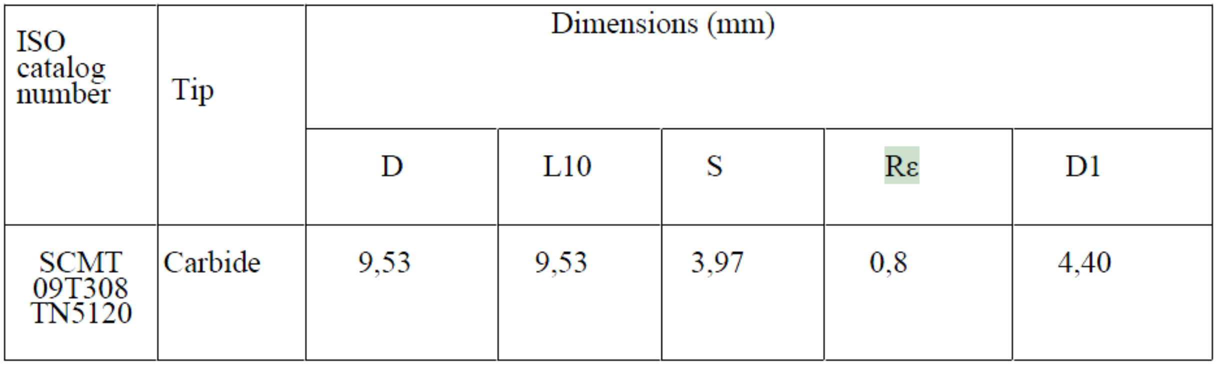


Figure 2.2 Carbide insert [21]

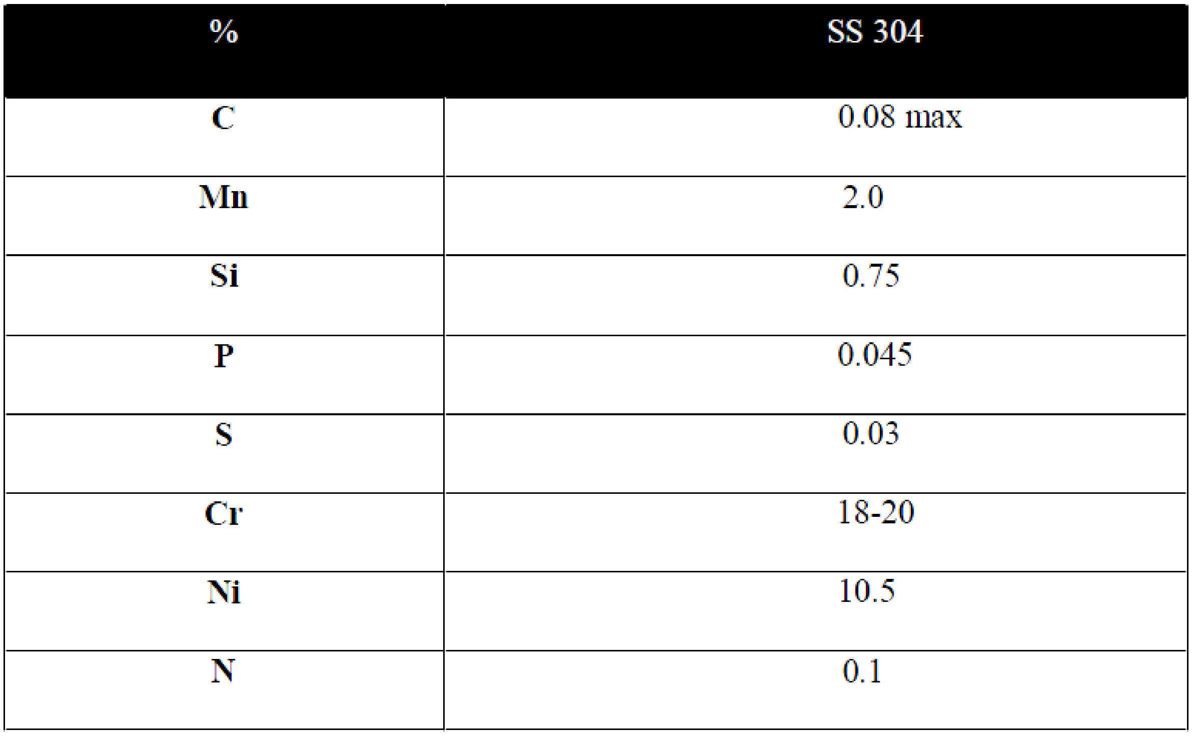


ISO catalog number	Tip	Dimensions (mm)				
		D	L10	S	Rε	D1
SCMT 09T308 TN5120	Carbide	9,53	9,53	3,97	0,8	4,40

Table 2.1 Specification of cutting tool

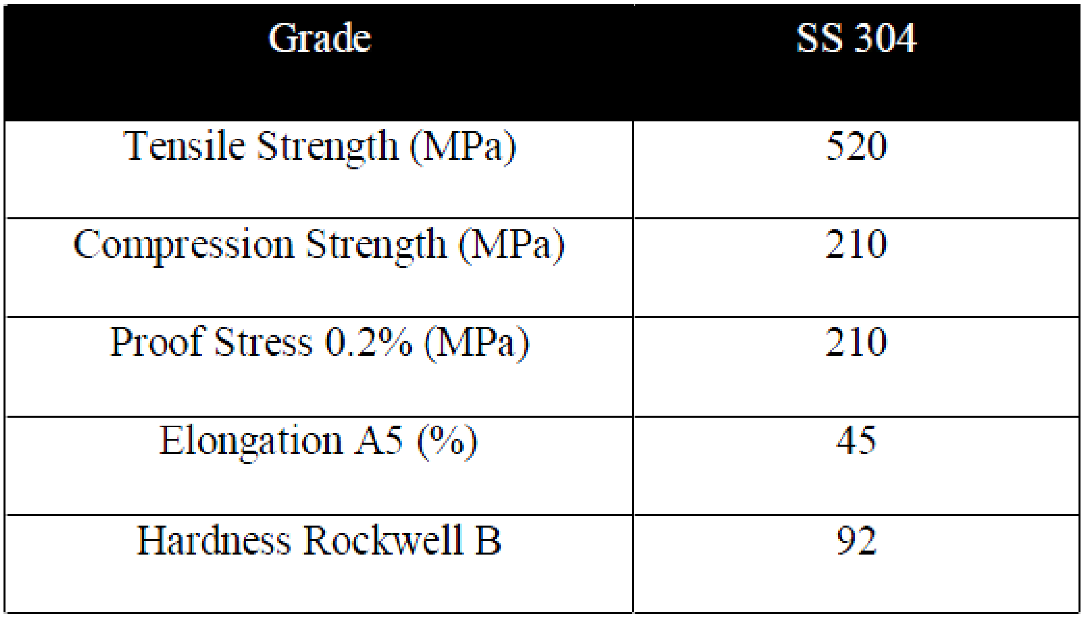
2.2. Composition of workpiece

Stainless Steel 304 of diameter 30mm was used in the project work. Stainless Steel 304 is an austenitic grade which provides excellent confrontation to corrosion and can also be easily welded [19].



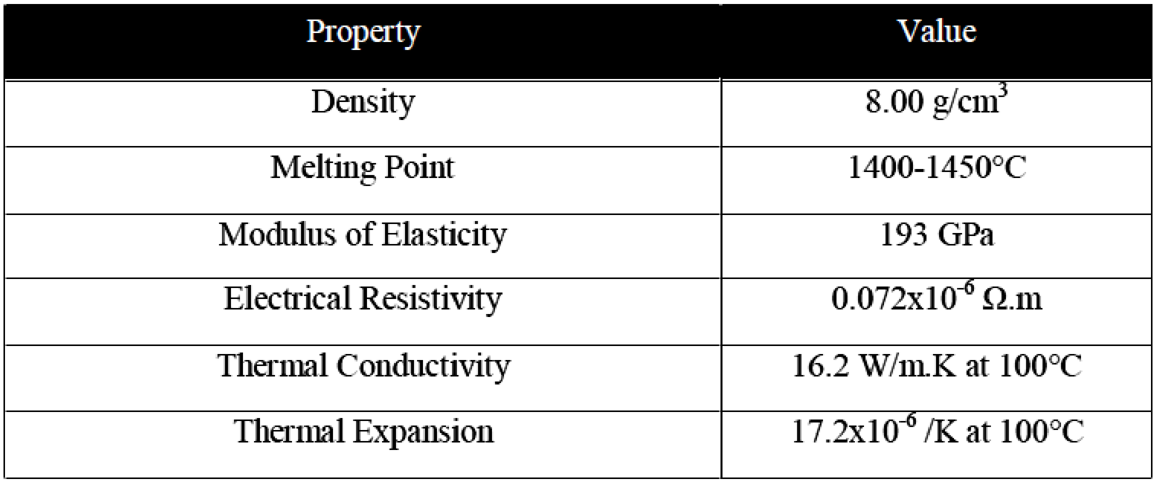
%	SS 304
C	0.08 max
Mn	2.0
Si	0.75
P	0.045
S	0.03
Cr	18-20
Ni	10.5
N	0.1

Table 2.2 Chemical Properties [20]



Grade	SS 304
Tensile Strength (MPa)	520
Compression Strength (MPa)	210
Proof Stress 0.2% (MPa)	210
Elongation A5 (%)	45
Hardness Rockwell B	92

Table 2.3 Mechanical Properties [20]



Property	Value
Density	8.00 g/cm^3
Melting Point	1400-1450°C
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.072x10^{-6} Ω.m
Thermal Conductivity	16.2 W/m.K at 100°C
Thermal Expansion	17.2x10^{-6} /K at 100°C

Table 2.4 Physical Properties [20]

2.3. Dynamometer

Optimization of cutting parameters requires accurate measurement of forces. For this purpose we use a device called dynamometer. It measures component of forces in a particular co-ordinate system. A satisfactory dynamometer design involves a compromise between structure that allows highest sensitivity at sufficient stiffness and rigidity so that geometry is maintained.

Figure 2.3

Cutting force cannot be measured directly. When a force acts on a material it undergoes a particular deformation. This deformation can be measured and hence the acting force. So the dynamometer is designed basing upon the principle to measure the deflection or strains induced in the dynamometer structure caused by resultant cutting force.

\2.4. Vibrometer

[22] The Vibrometer used in this project work is named as TV 300 vibration tester. It is constructed by piezoelectric acceleration transducer. It converts the vibrational signal to electric

signal. It analyses the input signal and measures peak acceleration, rotational speed and natural frequency.

Figure 2.4

It measures acceleration in peak, velocity in r.m.s and displacement in peak to peak. It shows peak acceleration in the range (0.1-392 m/s^2), r.m.s velocity (0.01-80 cm/s) and peak to peak displacement (0.0001-10mm).

2.5 Procedure Followed

First working of Vibrometer and dynamometer is checked taking some runs. Then in the automated lathe machine SS304 cylindrical workpiece is clamped between headstock and tailstock. According to design experiment cutting parameter and principal cutting edge angle are set. Then workpiece is given an initial roughing pass. 9 equal parts of 10mm on 30 mm diameter workpiece are marked equally leaving some space for confirmatory test. Then by changing different cutting parameters and cutting edge angle readings are taken for analysis. To decide the level of parameters Taguchi design of experiment is employed.

FACTORIAL SETTINGS CODED

SL NO.	CUTTING SPEED	FEED RATE	DEPTH OF CUT	PRINCIPAL 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 2.5

Then using dynamometer cutting forces are measured and using Vibrometer vibration in terms of peak to peak displacement is obtained for each test respectively.

Fig 2.5

Fig 2.6

CHPTER 3

METHODOLOGY USED

3.1. Taguchi Method

It is a statistical method used to improve the quality of manufactured product [23]. According to Taguchi [24] “Quality is the loss imparted to society from the time a product is shipped.” Science experimental procedures are generally expensive and time consuming we need to satisfy the design objective with minimum number of tests. Taguchi method involves laying out the experimental condition using orthogonal array. It is a specially constructed table which ensures that experiment design is both straight forward and consistent. By adopting this method number of analytical exploration needed to get the required design is significantly reduced. Hence testing time and experimental cost both are reduced. Orthogonal array provides much reduced variance for the experiment resulting optimum setting of process control parameter. It is carried in three step approach i.e. system design, parameter design, tolerance design. In system design, scientific and engineering principles are used to generate a prototype of the product that will encounter functional requirements. Parameter design is to optimize the settings of process parameter values for enlightening 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 attained by the settings identified in the parameter design stage is unacceptable. [25]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: $S/N_T = 10\log(\bar{y}/s^2)$

Larger is the better (maximize): $S/N_L = -10\log 1/y \sum^{n}_{i=1} 1/y_i^2$

Smaller is better (minimize): $S/N_S = -10\log 1/y \sum^{n}_{i=1} y_i^2$

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

3.2. Grey Relation Analysis

In the modern technically advanced industry grey relation analysis is one of the most important optimization methods which is proposed by Deng [26]. It is a method which measures the degree of approximation among sequences according to the grey relational grade. The interest of Researchers is very much attracted by the theory of grey relation analysis. In this analysis the measured values of responses (here cutting force and tool vibration) are first normalized in the range between zero to one which is also called grey relational generation. The normalized data corresponding to lower the better (LB) criterion can be evaluated on following expression,

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max\ y_i(k) - \min\ y_i(k)}$$

Similarly the normalized data corresponding to higher the better (HB) criterion can be evaluated on following expression,

$$x_i(k) = \frac{y_i(k) - \min\ y_i(k)}{\max\ y_i(k) - \min\ y_i(k)}$$

where $x_i(k)$ is the value after the grey relational generation, min y_i (k) is the smallest value of y_i (k) for the k_{th} response, and max y_i (k) is the largest value of y_i (k) for the k_{th} response. An ideal sequence is $x_0(k)$ for the responses. [i=1,2,3…….,25].

Then, the grey relational coefficients are obtained from the normalized experimental values to express the relationship between the desired and actual experimental results for both the responses. The grey relational coefficient can evaluated as

$$\xi_i(k) = \frac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{0i}(k) + \psi\Delta_{\max}}$$

Where $\Delta_{0i} = \| x_0(k) - x_i(k) \|$, ψ is the distinguishing coefficient $0 \le \psi \le 1$;

After that, grey relational grades are calculated by averaging the grey relational coefficient corresponding to each performance characteristic [27].

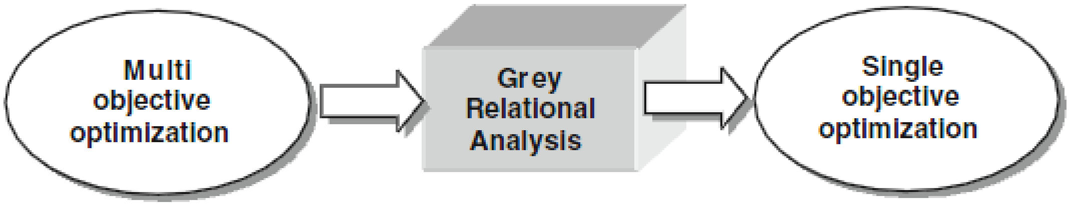


Fig 3.1 [17]

The overall response of the multiple performance characteristic is based on the grey relational grade which our objective function. In this way optimization of complicated multiple objective characteristics can be converted into optimization of a single grey relational grade. The grey relational grade can be obtained as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

Higher grey relational grade implies that the corresponding parameter combination is closer to the optimal set of input parameters. One having maximum S/N ratio (using HB criterion) is the optimal parameter setting. The S/N ratio for the overall grey relational grade can be represented graphically from which optimal combination is obtained [28].

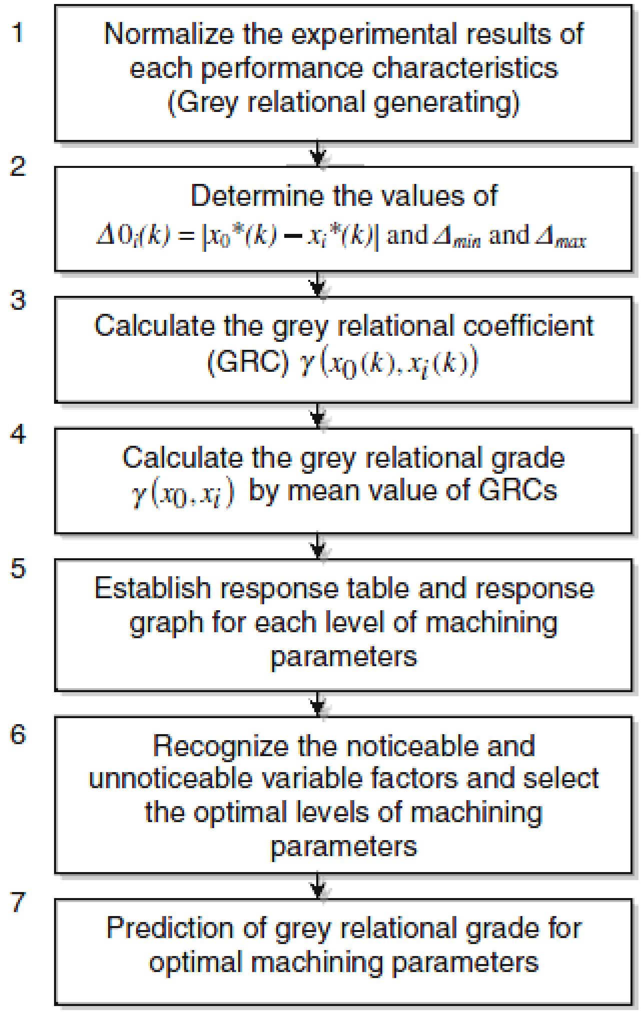


Fig 3.2 Flow chart for grey relation analysis [17]

CHAPTER 4

4. Experimental observation & Analysis

Taguchi design of experiment is used to collect the data of cutting force and tool vibration. Minitab16® software is used to find the s/n ratio of grey relation grade and hence the optimal setting of input parameter. [29]Minitab 16 software is used in this project work because it gives an easy technique to create, alter and review graphs. It also offers an active link between a graph and its worksheet hence helps in updating the graph automatically whenever the data is changed. Its user-friendliness and appearance also add to its effectiveness.

Data analysis has been conducted by the procedural order as shown below:

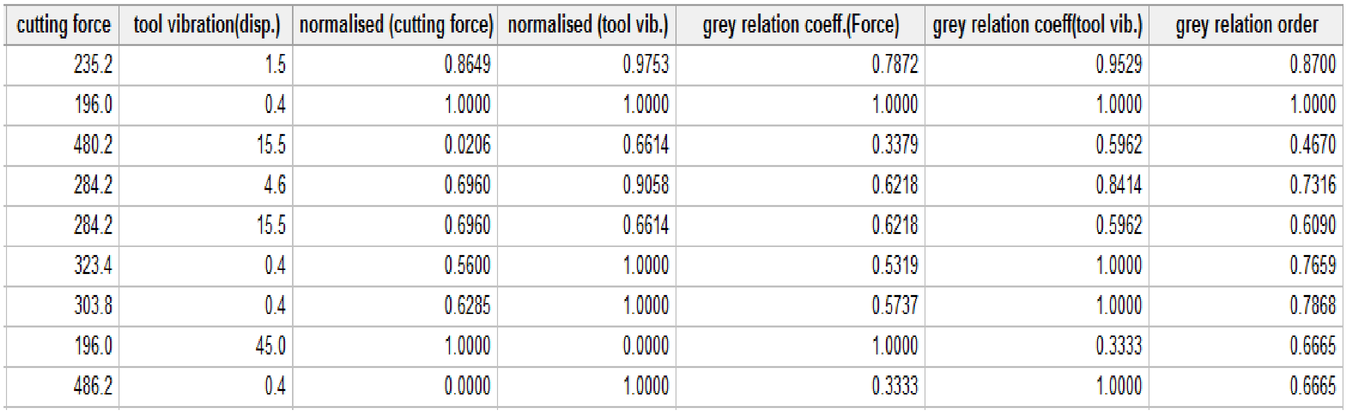
1. Normalization of experimental data (cutting force and tool vibration) is done using grey relation analysis for lower the better (LB) criterion as we need optimal solution for minimum cutting force and tool vibration.
2. Grey relation coefficient corresponding to individual responses for both cutting force and tool vibration is determined.
3. Grey relation grade is obtained from the formula given in G.R.A which is the combination of grey relation coefficient of both the responses.
4. S/N ratio of grey relation grade is obtained and main effect is plotted for higher the better (HB) criterion from which optimal solution is found out.
5. Response table for s/n ratio is obtained in Minitab 16 software from which the effectiveness of input parameters is defined.

factors	symbol & unit	code	levels of factors		
			1	2	3
Cutting speed	N(m/min)	A	13.18	20.724	33.912
feed rate	f(mm/rev)	B	0.105	0.16	0.25
depth of cut	d(mm)	C	0.5	0.6	0.7
principal cutting edge angle	Ø(degree)	D	78	66	62

Table 4.1 Domain of experiments

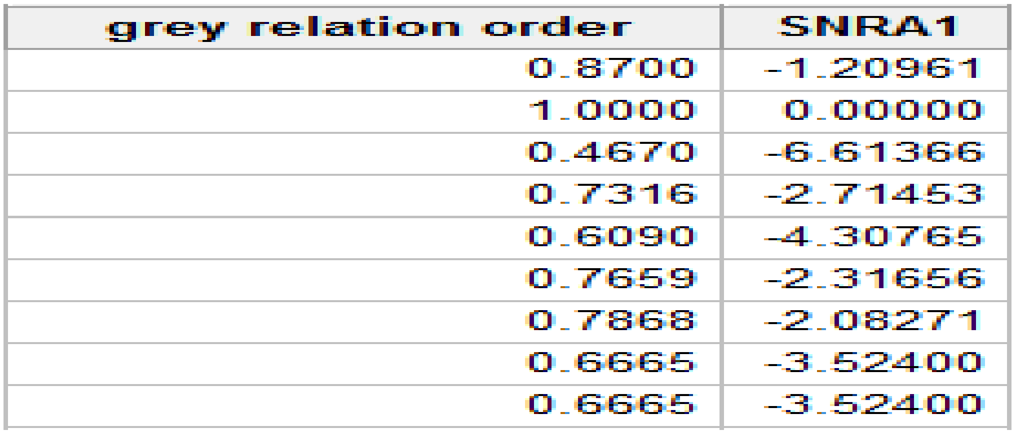
Table 4.2

factorial setting (coded)				**Experimental Data**	
A	**B**	**C**	**D**	**CUTTING FORCE (N)**	**PEAK TO PEAK DIS (um)**
1	**1**	**1**	**1**	**235.2**	**1.5**
1	**2**	**2**	**2**	**196**	**0.4**
1	**3**	**3**	**3**	**480.2**	**15.5**
2	**1**	**2**	**3**	**284.2**	**4.6**
2	**2**	**3**	**1**	**284.2**	**15.5**
2	**3**	**1**	**2**	**323.4**	**0.4**
3	**1**	**3**	**2**	**303.8**	**0.4**
3	**2**	**1**	**3**	**196**	**45.0**
3	**3**	**2**	**1**	**486.2**	**0.4**



cutting force	tool vibration(disp.)	normalised (cutting force)	normalised (tool vib.)	grey relation coeff.(Force)	grey relation coeff(tool vib.)	grey relation order
235.2	1.5	0.8649	0.9753	0.7872	0.9529	0.8700
196.0	0.4	1.0000	1.0000	1.0000	1.0000	1.0000
480.2	15.5	0.0206	0.6614	0.3379	0.5962	0.4670
284.2	4.6	0.6960	0.9058	0.6218	0.8414	0.7316
284.2	15.5	0.6960	0.6614	0.6218	0.5962	0.6090
323.4	0.4	0.5600	1.0000	0.5319	1.0000	0.7659
303.8	0.4	0.6285	1.0000	0.5737	1.0000	0.7868
196.0	45.0	1.0000	0.0000	1.0000	0.3333	0.6665
486.2	0.4	0.0000	1.0000	0.3333	1.0000	0.6665

Table 4.3



grey relation order	SNRA1
0.8700	-1.20961
1.0000	0.00000
0.4670	-6.61366
0.7316	-2.71453
0.6090	-4.30765
0.7659	-2.31656
0.7868	-2.08271
0.6665	-3.52400
0.6665	-3.52400

Table 4.4

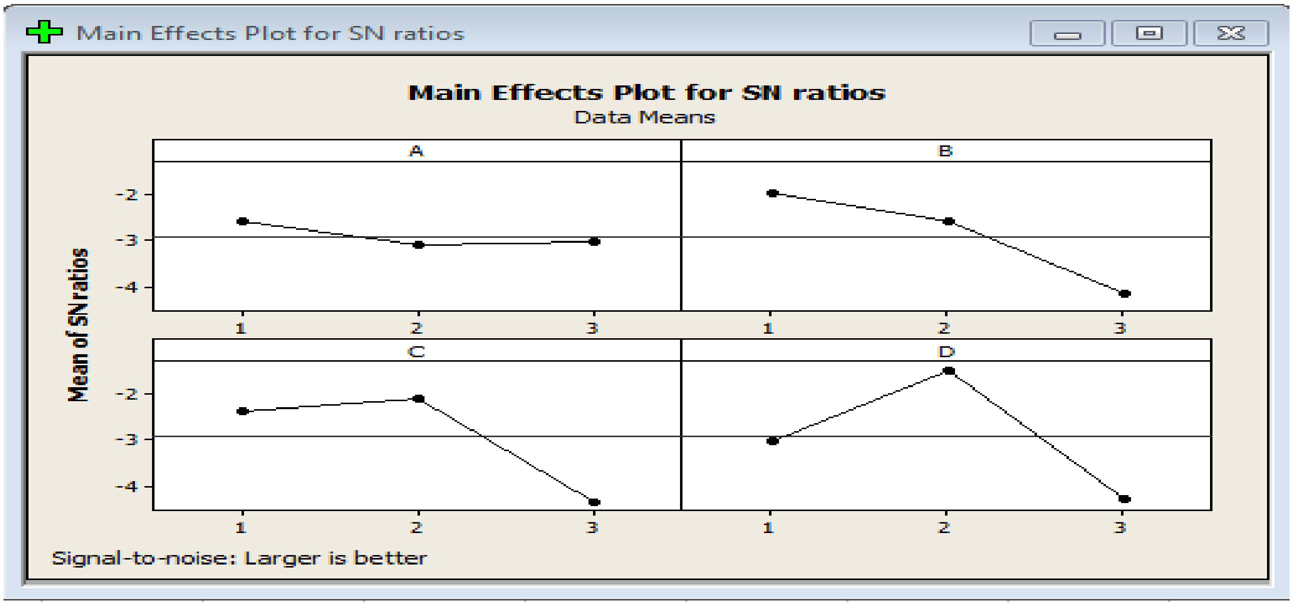

Main Effects Plot for SN ratios
Main Effects Plot for SN ratios
Data Means
A
B
C
D
Mean of SN ratios
-2
-3
-4
1
2
3
Signal-to-noise: Larger is better

Fig 4.1

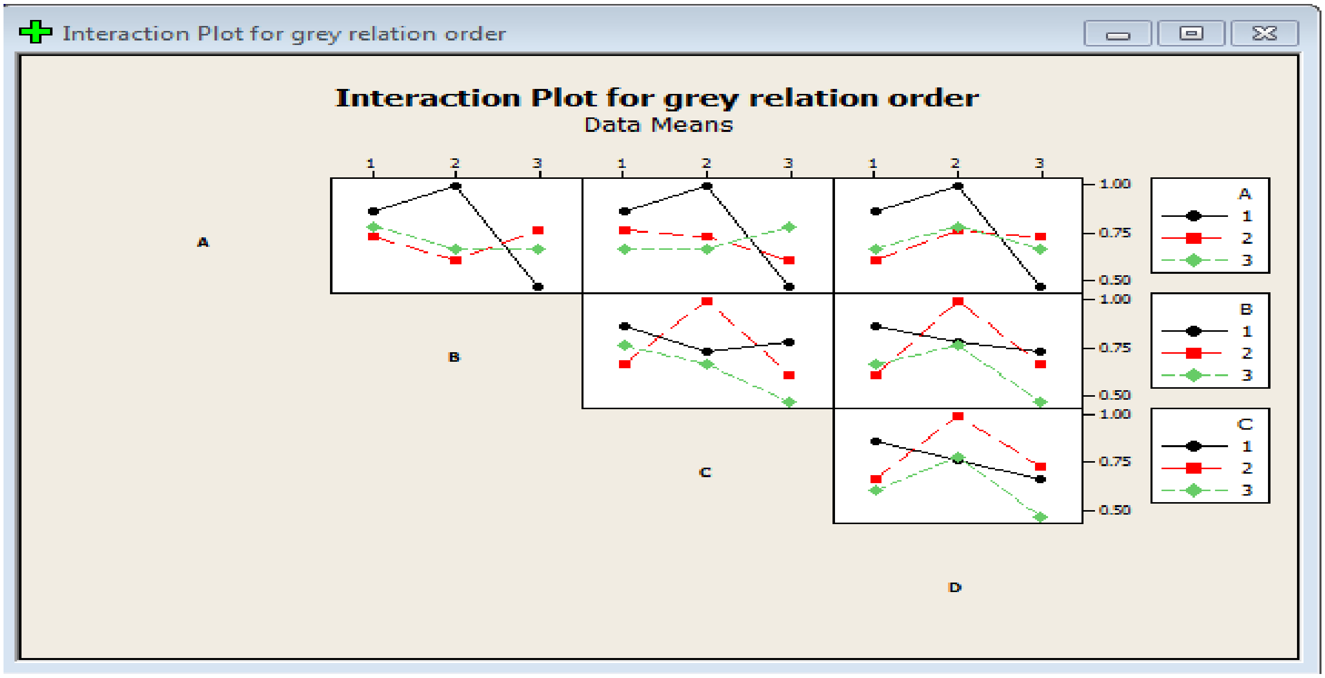
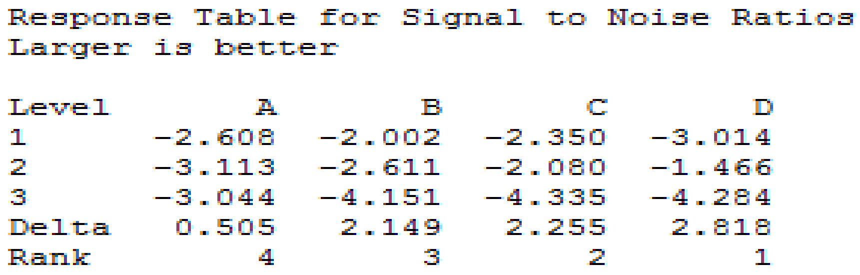

Interaction Plot for grey relation order
Interaction Plot for grey relation order
Data Means
1
2
3
1.00
0.75
0.50
A
B
C
D
A 1 2 3
B 1 2 3
C 1 2 3

Fig 4.2



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Response Table for Signal to Noise Ratios
Larger is better

Level        A       B       C       D
1       -2.608  -2.002  -2.350  -3.014
2       -3.113  -2.611  -2.080  -1.466
3       -3.044  -4.151  -4.335  -4.284
Delta    0.505   2.149   2.255   2.818
Rank         4       3       2       1
```

Table 4.5

CHAPTER 5

5. Conclusions and Recommendation

5.1. Conclusions

The following conclusions can be drawn after the experiment and study on turning of SS 304 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 study it is found that the main factors affecting more the cutting force and tool vibration are principal cutting edge angle and depth of cut. Cutting speed and feed rate are less affecting as compared to the above two mentioned parameters. The two responses cutting force and tool vibration are combined together to one.
3. The optimal setting is found to be A1B1C2D2. A confirmatory test is carried out after the optimal setting of input parameters is determined. The optimal value of cutting force is found to be 284.2 N. The optimal value of tool vibration in terms of peak to peak displacement is found to be 0.3um.

5.2. Recommendation

Plenty of research work has been carried out on optimizing cutting parameters and tool geometry. Effect of these parameters can be analyzed by taking other workpiece and tool material. Apart from cutting speed, feed and depth of cut and geometric parameter other parameters like tool nose radius, use of cutting fluid can be taken into account to find optimal setting of input parameters. Artificial Neural Network method (ANN), Regression analysis, fuzzy logic, principal component analysis can also be used to get the optimum data.

CHAPTER 6

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