Multi Objective Optimization of Cutting and Geometric parameters in turning operation to Reduce Cutting forces and Surface Roughness

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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 and geometric parameters in turning operation to cutting force and surface roughness** submitted by ***Shri Gautam Kumar*** has been carried out under my supervision in partial fulfillment of the requirement for the Degree of ***Bachelor of Technology*** in ***Mechanical Engineering*** at National institute of technology, Rourkela and this work hs not been submitted elsewhere before for any other academic degree.

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ABSTRACT

Turning operation is one of the most important machining operations to be carried out in different industries for manufacturing of various products. As it is a basic operation for various industries it is very essential to optimize the various parameters affecting turning operation for the optimum operating condition. Turning operation is affected by both cutting parameters and geometrical parameters. The parameter influence most are cutting velocity, depth of cut , feed rate, geometry of cutting tool like principle cutting edge angle ,rake angle, nose radius etc. In order to control surface roughness and cutting force acting on material during turning operation it is very necessary to control these parameters as the product with desired attributes are function of these parameter.

The objective of the project is obtain the optimum values of different cutting parameter like cutting speed , depth of cut, feed rate and principle cutting edge angle for the minimum cutting force and surface roughness.

In the project turning operation of 304 SS as work piece is carried out with WC inserts as tool. The different values of cutting parameters, cutting speed (13.18, 20.724, 33.912 m/min), feed rate (0.105, 0.166, 0.25mm/rev), depth of cut (0.5, 0.6, 0.7mm) and principle cutting edge angle (78, 66, 62 degree) are selected.

Different combinations of experiments are designed and conducted based on Taguchi's L_9 orthogonal array design. Grey relational coefficients are determined after normalizing the value of output responses for lower-the-better condition and after that grey relation grade is obtained. Grey relation grade value are converted in S/N ratio for larger-the-better condition in MINTAB 16 and based on the plot of S/N ratio in MINTAB 16 the optimal levels of the input parameters are identified. Confirmation test is conducted for the optimal level of input parameters to validate the experimental result.

Key Words: Cutting force, Surface roughness, Multi-objective optimization, Orthogonal Array, Grey relational Analysis.

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Chapter 1

1.1 INTRODUCTION

Today metal cutting is significant industry in most economically developed countries. Of all the processes used to shape the metals, the conditions of operation are most varied in machining. Machining is most widely used process to produce different shape used in engineering world.

Turning is the machining operation which widely used in industries for machining. During turning operation the work material is held in the chuck and rotated and tool is held rigidly in a tool post and moved at constant rate along the axis of the work material, cutting away the layer of metal from work piece to form a cylinder or other complex profile. The turning operation is controlled by cutting and the geometry parameters. The cutting parameters include cutting speed, feed rate and depth of cut.

The cutting speed is defined as the rate uncut surface of the work material passes the cutting of tool and usually expressed in ft/min or m/min. the feed rate is the distance moved by tool in the axial direction at every revolution of work material. The depth of cut is the thickness of material removed from the work material in the radial direction. The cutting speed and the feed rate are the two most influential cutting parameters during tuning operation and it should be controlled by operator to achieve optimal cutting condition.

Traditionally selection of cutting parameters for turning is left to machine operators but in this case even for a skilled operator it is very difficult to obtain the optimum values of the parameter. To determine the good quality characteristic it is very necessary to set optimum value of the parameters.

To predict the optimum value of different parameters we use optimization technique. Using a optimization technique we can evaluate the optimum values for different cutting and geometry parameter for which we achieve optimum economic performance of the operation. In turning operation we perform multi-objective to establish a tradeoffs between various input parameters to achieve desired value of the responses. In turning operation the machining performances are measured by different responses such as tool life, material removal rate, surface roughness, cutting force. These performances measures significantly influence the economic performance of machining, such as production cost, profit rate etc.

Manufacturing of any product includes various types of process and in today's world manufacturing processes are caught between the growing needs for quality, high manufacturing costs, high process safety and short manufacturing times. In order to meet the required demand, manufacturing process control parameters should be chosen in the best possible manner. The selection of optimum process parameter plays an important role to ensure quality of the product, reduce manufacturing cost and to increase production rate. Modeling and optimization of the input process parameters is one of the difficult task and these required following aspects: knowledge of manufacturing process, empirical formula to develop realistic constrains, specification of machine capabilities, development of an effective optimization criterion and knowledge of mathematical and numerical optimization techniques.

Cutting force and surface roughness are two most important technological parameters in machining process. Cutting force directly influence on cutting pressure and power consumption, heat generation, tool wear, deformation of work piece machined, its dimensional accuracy, chip formation and machining system stability. It is the necessary for the evaluation of power machining (choice of electric motor). Surface roughness is related to many properties of machine elements like wear resistance, friction and heat transmission.

1.2 Literature Review

Ahilan C, Kumanan, S & Sivakumaran,N [12] they conducted and designed experiment on CNC machine with AISI304 as work material and Carbide tool inserts to study and optimize the turning parameters using taguchi and grey relation method. They have taken four parameters cutting speed, depth of cut, feed rate and nose radius and these parameters effect on power consumption and surface roughness. Experiments were conducted on the basis of L_{27} orthogonal array and after that grey relation method was used to optimize the multi response of power consumption and surface roughness. Using the grey relation grade ANOVA is used to determine the contribution of different factor. They observed that the cutting speed affects the most followed by feed rate, depth of cut and nose radius.

H.L Shyu and L.L Hsieh [9] studied the optimization of UV/H_2O_2 and UV/TiO_2 process for copper complexes using taguchi's experiment design . They used five control factors pH solution, Kind of catalyst, capacity of H_2O_2 , kind of amino carboxylic acid, the ratio of cu^{2+} and amino carboxylic acid and three different levels and used L_{18} orthogonal array. The result showed that the photo degradation reduced by 97.8% with the presence of H_2O_2. . It also showed that effect of catalyst was insignificant.

Emel Kuram, Babur Ozcelik [8] studied the micro-milling of aluminum metal with ball nose end mill. It was carried out in four stages: experimental work, modeling and multi- optimization.

The control parameters were spindle speed, depth of cut on tool wear and feed per tooth. Their effect on force on surface roughness was investigated. Taguchi design of experiment was used to carry out the experiment. The effect of input parameters on the responses was evaluated by analysis of variance. After that grey relation methd is used to estimate the optimum combination of input parameter for minimum value of tool wear, cutting force and surface roughness. It was also concluded that spindle speed is the most significant parameter among the parameters.

C.L.Lin[7] studied the approach based on taguchi method in combination with grey relation analysis for th optimization of turning operation of S45C steel bars with multi-performances responses. Optimal cutting parameters were estimated by using grey relation grade as the performance index. The control parameters were cutting speed, feed rate and depth of cut and each having three levels. The orthogonal array used was L_9. The grey relation analysis of cutting force, tool life and surface roughness can convert the multiple objective characteristic in single characteristic known as grey relation grade. The result also showed that Grey relation method is can be efficiently used for multi-response optimization for different machining process.

Chapter 2

2.1 Work piece

SS 304 is the most extensively used stainless steel, available in wide variety of products, forms and finishes. It is having an excellent welding and forming capacities. The balanced austenitic structure of grade 304 can be deep drawn without any intermediate annealing. SS 304 can be readily brake or roll formed into various components for application in the industrial, transportation and architectural fields. It has two types:

304L, the low carbon version which does not require post weld-annealing and therefore it is widely used in heavy gauge components.

304H is having high carbon content and it has application at elevated temperature. It has high toughness.

Chemical composition of SS 304

Table 1 Chemical composition of SS 304

GRADE	C	Mn	Si	P	S	Cr	Mo	Ni	N
304	0.08	2.0	0.75	0.045	0.030	20.0	-	10.5	0.10

Mechanical properties of SS 304

Table 2 Mechanical properties of SS 304

GRADE	Tensile strength(Mpa)	Yield strength 0.2% proof (MPa)	Elongation (% in 50 mm)	Rockwell hardness (HR B)	Brinell hardness (HB)
304	515	205	40	92	201

SS 304 is widely used material and have application in different fields like :

- Food processing equipment like in milk processing.
- Architecture paneling and trim.
- Chemical containers and heat exchangers.
- Threaded fasteners and springs.

2.2 Tool specification

Tool used for turning of the 304 SS was carbide inserts.

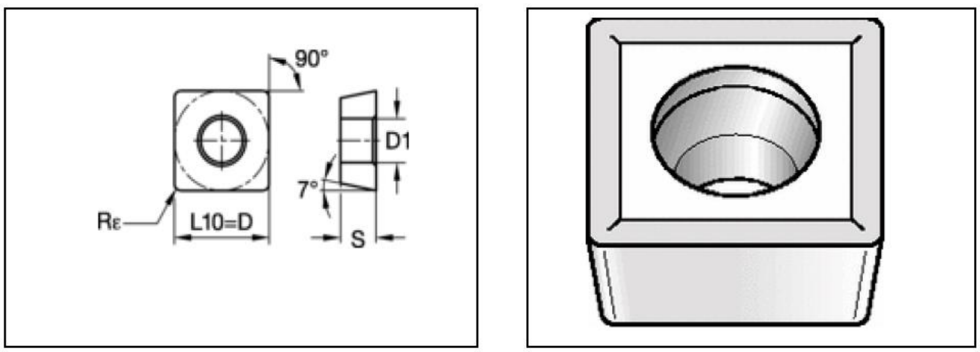

Figure 1 Cutting tool

Table 3 Tool Specification

ISO catalog number	Tip	dimension				
		D	L10	S	R_e	D1
SCMT 09T308TN5120	Carbide	9.53	9.53	3.97	0.8	4.40

2.3 Equipment used

2.3.1Dynamometer

The forces during turning operation are measured using dynamometer. This device is the most reliable method for measuring cutting forces. It is inserted either between the tool and machine as a dynamometer-type tool holder or between the work and machine as work holding type dynamometer. In our case we have used tool holder type dynamometer. It is capable of measuring two or three forces at a time depending upon the complexity of the dynamometer. The net power and other properties can be calculated from these force components. There are two types of dynamometer used for measurement of forces: mechanical type dynamometer and electrical strain dynamometer. In our case we used electrical strain guage dynamometer. It is common in use and it is more accurate. The basic principal of strain gauge dynamometer is shown in figure .

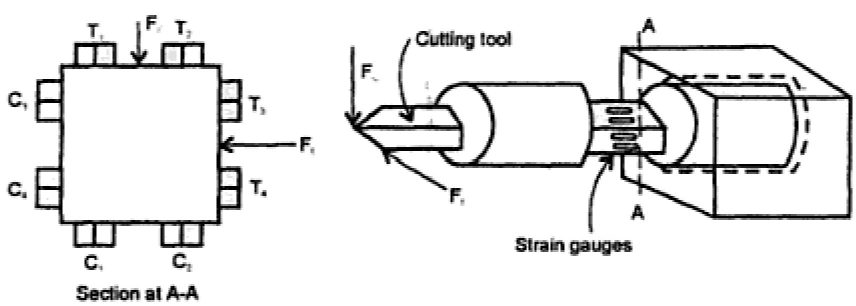

Figure 2 Dynamometer

2.3.2 Talysurf

It is a stylus and skid based instrument in which magnification are evaluated electrically. The response of talysurf is more rapid and most accurate. In this instrument sharply pointed stylus is used to trace the profile of turning surface and the oscillatory movement of the stylus is converted into corresponding change in electric current. The profile of the surface irregularities are thus converted into electrical quantity. The diamond stylus which traces the profile of the irregularities has a tip of dimension 0.001 inch and act on the surface with a force of rmine the 0.1gm.talysurf is based on the principle of running probe along the surface and determine the variation in height of the surface as a function of distance.some error can be incorporated during the measurement of surface roughness due to stylus speed and lateral deflection due to unevenness of the surface.

Figure 3 Handysurf

The handysurf measures the different surface roughness parametrs like R_a, R_{sm}, R_z, and $R_{p.}$

The most common surface roughness parameter is average roughness R_a. surface roughness average (R_a) is also known as arithmetic average (AA) and is rated as the arithmetic average deviation of surface peaks and valleys expressed in micro inches or micro meters. It can be measured by following formula:

R_a = CLA=AA= $(M_1 + M_2 + \ldots.. + M_n)/n$

Where M_x = measure value

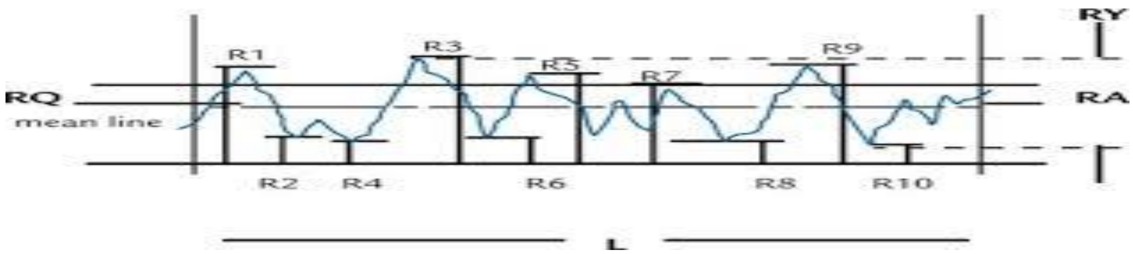

Figure 4 Surface roughness (R_a)

Chapter 3

3.1 Methodology

The design of experiment was done by using taguchi method and multi-objective optimisation is done by grey relational analysis method.

3.1.1Taguchi method

Genichi taguchi a Japanese engineer devised a experimental design principle which is used for quality engineering. According to taguchi "quality is the loss imparted to society from the time a product is shipped". The concept of taguchi method is to design a levels of each parameters so to reduce the deviation in characteristic from its target value. He used the concept of orthogonal array to study large number of combination of variables in small number of experiments. At the core of product and process design is the concept of experimental design. The method according to which we design our experiments guide in selecting combinations of the various factor levels that enable us to determine the output characteristic and thereby calculating the performance statistic. An orthogonal array represents a matrix of numbers. Each row represents the levels or states of choosen factors and each column represents a specific factor whose effect on the response variable are of interest. Orthogonal array is having a property that every factor setting occurs the same number of times for every test setting of all other factors. This allows us to made balanced comparison among factors level under variety of conditions.

Taguchi recommends the use of loss functions to determine process response deviation from thr desired value. The value of loss function is further converted into signal-to-noise(S/N) ratio and tries to select the parameter levels that maximize this ratio. The term signal represents the square of the mean of the quality characteristic while noise is a measure of the variability of the characteristic.

There are three categories of output characteristic in the analysis of S/N ratio, these are : Higher-the-better, lower-the-better and nominal-the best. The S/N ratio can be evaluated by following formula:

For nominal the best

S/N T = $10\log\left(\frac{y}{s2}\right)$

For Higher-the-better

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

For lower-the-better

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

Where y is the observed data and n is the number of observation.

The method is most relevant for the optimization of single response. in the multi-objective optimization the lower S/N ratio of one response may c for optimization of multi-response to higher S/N ratio of other there for resultant S/N ratio of the responses are required for the optimization of multi-response. For this purpose we must adopt another method in combination with taguchi method. Here we have used Grey relational analysis.

3.1.2 Grey Relational Analysis

In the grey relational analysis, experimental data of the output responses are first normalized between the ranges of 0 to 1. This process is known as grey relational generation After normalization grey relational coefficient are calculated to express relationship between actual and desired experimental data. Then overall grey relational grade is calculated by averaging the grey relational coefficient of the output responses. The overall quality characteristic of the multi-objective process depends on the determined grey relational grade.

Grey relational generation

The obtained experimental data for output responses can be normalized according to different requirement. There are three different normalization condition lower-the-better, higher-the-better and nominal the best criteria. The normalized data corresponding to lower-the-better can be evaluated by:

$$X_i(k) = \frac{\max Yi(k) - Yi(k)}{maxYi(k) - minYi(k)}$$

For higher-the-better condition normalized data value can be evaluated by:

$$X_i(k)=\frac{Yi(k)-minYi(k)}{maxYi(k)-minYi(k)}$$

Where X_i is the value obtained after grey relational generation. $minY_i(k)$ is smallest value of Y_i and max $Y_i(k)$ is the maximum value of $Y_i(k)$.

Grey relational coefficient

The grey relational coefficient is calculated by following equation:

$$\gamma_i = \frac{\Delta min+\zeta\Delta max}{\Delta oi(k)+\zeta\Delta max}$$

Where γ_i the grey relational coefficient of the I^{th} experiment for the k^{th} response. $\Delta_{oi}=||X_o(k)-X_i(k)||$=difference between absolute value, ζ the distinguishing coefficient and it is defined in the range $0 < \zeta \leq 1$,$\Delta min= min|| x0(k)-xj(k)||$ is the smallest value of Yj(k) and $\Delta max= max||x(k)-xj(k)||$ is the largest value of Yj(k).

Grey relational grade

The grey relational grade is calculated by averaging the grey relation coefficients corresponding to each experiment.

$$\alpha_i = \frac{1}{n} \sum_{k=1}^{n} \gamma i(k)$$

Where n is total number of responses.

3.2 Procedure followed

According to above discussion following steps have been followed for the multi-objective optimization of the turning operation using Taguchi and Grey Relational Analysis.

1. The cutting parameters and geometric parameters for turning operation are selected.

Cutting parameters:

- Cutting speed
- Feed rate
- Depth of cut

Geometry parameter

- Principal cutting edge angle

Three levels of each of cutting parameters and geometric parameters are selected.

Table 4 levels of Input Parameters

level	Cutting speed (m/min)	Feed rate (mm/rpm)	Depth of cut (mm)	Principal cutting edge angle (Degree)
1	13.18	0.105	0.5	78
2	20.724	0.166	0.6	66
3	33.912	0.25	0.7	62

2. For 4 input parameters and 3 level an orthogonal array L_9 is selected using **MINITAB16.**

Table 5 Design Of Experiment L_9 Orthogonal array

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

Now based on arrangement of the orthogonal array table (5), turning of the work piece is carried out using carbide tool on the lathe. 304 SS work piece is centered and properly fitted on the headstock. First a rough pass was given to the work piece and diameter of work piece was made to 30mm.

Figure 5 Experimental Setup

Chapter 4

4.1 Experimental observation and result

For each combination of input parameters according to orthogonal array, cutting force and surface roughness is determined using dynamometer and talysurf.

Table 6 Observation Table

Sl.no	Cutting speed (mm/min)	Feed rate (mm/rpm)	Depth of cut (mm)	Principle cutting angle	Force (N)			Surface roughness R_a (µm)
					Thrust	Feed	Radial	
1	13.18	0.105	0.5	78	235.2	107.8	98	2.6
2	13.18	0.166	0.6	66	196.0	117.6	88.2	1.5
3	13.18	0.250	0.7	62	480.2	294.0	235.2	1.3
4	20.724	0.105	0.6	62	284.2	235.2	176.4	0.8
5	20.724	0.166	0.7	78	284.2	176.4	147.0	0.7
6	20.724	0.250	0.5	66	323.4	196.0	147.0	0.8
7	33.912	0.105	0.7	66	303.8	245.0	176.4	0.9
8	33.912	0.166	0.5	62	196.0	137.2	137.2	1
9	33.912	0.250	0.6	78	486.2	196.0	235.6	1.2

3. After measurement of force and surface roughness, the value of cutting force (thrust force) and surface roughness is normalized using lower-the-better condition. For lower-the-better condition normalized formula is:

$$X_i(k) = \frac{\max Yi(k) - Yi(k)}{maxYi(k) - minYi(k)}$$

After normalization we obtained following table:

Table 7 Normalized value of cutting force and surface roughness

Sl.no	Cutting force	Surface roughness
1	0.8649	0.0000
2	1.0000	0.5789
3	0.0206	0.6842
4	0.6960	0.9473
5	0.6960	1.0000
6	0.5600	0.9473
7	0.6285	0.8947
8	1.0000	0.8421
9	0.0000	0.7326

After obtaining normalized data table () it has been used to calculate the quality loss estimates. Quality loss (Δ_{oi}) estimates for each normalized value are shown in table (8). It is estimated by

Δ_{oi}=$||X_o(k)-X_i(k)||$=difference between absolute value and $X_i(k)$. The value of X_{oi}= 1.

Table 8 loss quality estimate

Sl.no	Cutting force	Surface roughness
1	0.1351	1.0000
2	0.0000	0.4211
3	0.9794	0.3158
4	0.3040	0.0527
5	0.3040	0.0000
6	0.4400	0.0527
7	0.3715	0.1053
8	0.0000	0.1579
9	1.0000	0.2674

After evaluating loss quality estimates (Δ_{oi}) grey relation coefficient for cutting force and surface roughness is calculated. The grey relational coefficient γ_{ij} can be expressed as :

$$\gamma_{ij} = \frac{\Delta min+\zeta\Delta max}{\Delta oi(k)+\zeta\Delta max}$$

where,

ζ the distinguishing coefficient and it is defined in the range $0 < \zeta \leq 1$.

Δ_{min}= min|| $x_0(k)$-$x_j(k)$|| is the smallest value of $Y_j(k)$.

Δ_{max}= max||x(k)-$x_j(k)$|| is the largest value of $Y_j(k)$.

Table 9 Grey relation coefficient

Sl.no	Cutting force	Surface roughness
Ideal sequence	1.0000	1.0000
1	0.7872	0.3333
2	1.0000	0.5428
3	0.3379	0.6128
4	0.6218	0.9046
5	0.6218	1.0000
6	0.5319	0.9046
7	0.5737	0.8260
8	1.0000	0.7599
9	0.3333	0.6544

After averaging grey relation coefficient grey relation grade is obtained using equation

$$\alpha_i = \frac{1}{n} \sum_{k=1}^{n} \gamma i(k)$$

Where n= number of process responses.

Thus multi-objective optimization has been converted in single optimization. Table (10) shows the grey relational grade and order. The higher value of grey relation grade means that the corresponding input parameter is closer to optimal value.

Table 10 Grey Relation Grade

Sl no	Grey relational grade	order
1	0.5602	7
2	0.7714	3
3	0.4753	9
4	0.7632	4

5	0.8190	2
6	0.7182	5
7	0.6998	6
8	0.8799	1
9	0.4938	8

Now the S/N ratio plot for the grey relational grade has been calculated using MINITAB 16. the S/N ratio has been calculated for higher-the-better condition. The S/N plot for the grey relational grade is shown in the figure 6.

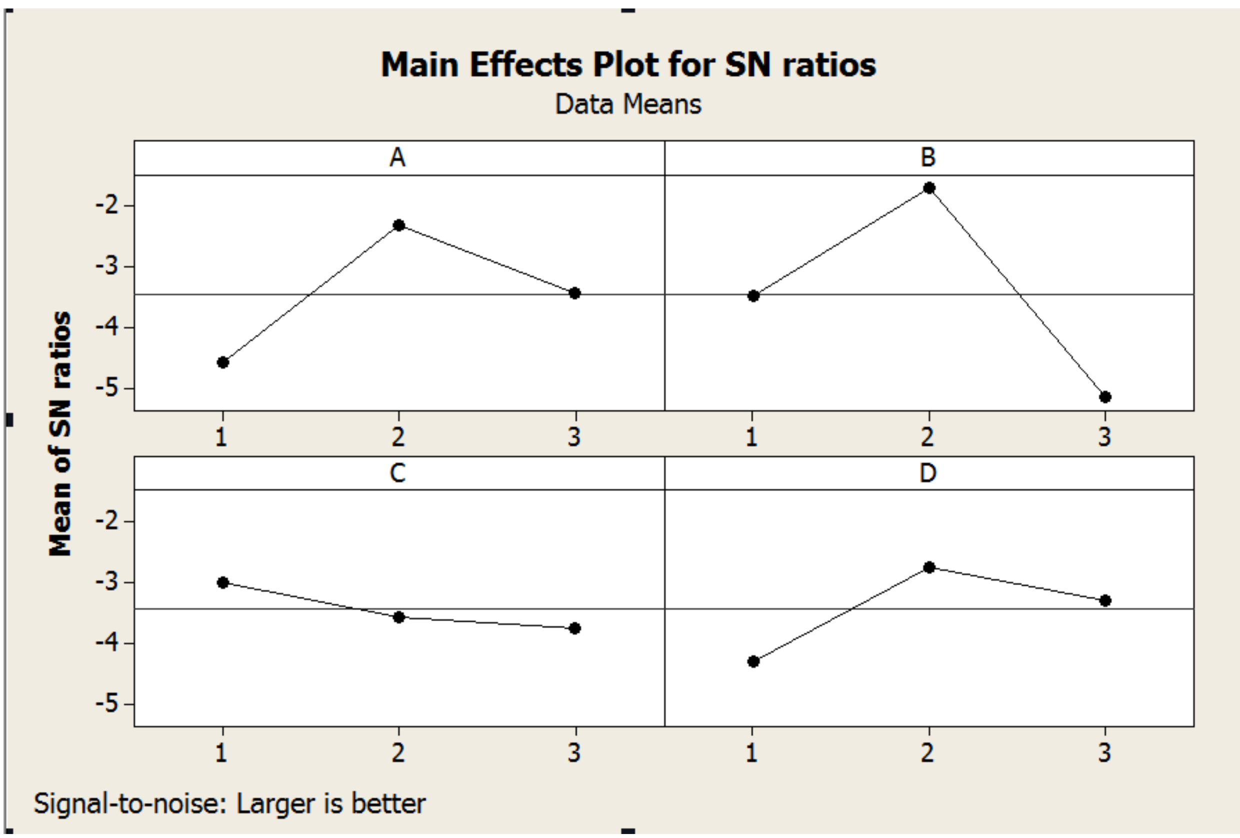

Figure 6 S/N ratio plot

With the help of S/N ratio figure optimal parametric combination of the input parameters has been determined.

The optimal setting of input factors is **A2 B2 C1 D2**.

```
Response Table for Signal to Noise Ratios
Larger is better

Level        A       B       C       D
1       -4.583  -3.494  -3.007  -4.299
2       -2.319  -1.700  -3.577  -2.743
3       -3.447  -5.155  -3.765  -3.306
Delta    2.264   3.455   0.759   1.555
Rank         2       1       4       3
```

4.2 Confirmatory test

For the optimal setting of the input parameters obtained from the minitab, experiment is performed and value of cutting force and surface roughness is obtained.

Table 11 cutting force and surface roughness value for optimal setting

Sl .no	Cutting speed (m/min)	Feed rate (mm/rpm)	Depth of cut (mm)	Force(N)			Surface roughness R_a (μm)
				Thrust	Feed	Radial	
1	20.724	0.166	0.5	186.2	127.4	137.2	2.4

For the obtained value of surface roughness and cutting force, S/N ratio is calculated according to previous steps and is compared with the S/N ratio evaluated from MINITAB 16 for input parameters A2 B2 C1 D2. The S/N ratio for the experimental run is -1.106 while S/N ratio by using MINTAB 16 for the same is -0.975681.

Table 12 confirmatory test

	Optimal cutting factors	
	Prediction (MINITAB)	experiment
level	A2 B2 C1 D2	A2 B2 C1 D2
CUTTING FORCE (N)		186.2
SURFACE ROUGHNESS(µm)		2.4
S/N RATIO (larger-the-better)	-0.975681	-1.1069

The S/N ratio value predicted by MINITAB 16 and S/N ratio by calculation for the Experimental optimal both are same so it can be concluded that the optimal setting A2 B2 C1 D2 is right optimal setting and turning for 304 SS should be done at this setting for minimum cutting force and surface roughness.

Chapter 5

Conclusion

After the experiment and analysis of the turning operation of 304 SS with carbide insert tool following conclusion can be made.

1. The optimization of multi-objective responses can be done efficiently and in simplified way by using Taguchi and grey relational analysis approach.

2. From the analysis it can be shown that feed rate and cutting speed are the main important input parameters which affect the cutting force and the surface roughness most.

3. By this technique the turning operation performance characteristic like cutting force and surface roughness can be improved together.

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