Determining the Effect of Cutting Parameters in CNC Turning

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Abstract - Turning is one of the most important metal cutting operations in industries. The process of turning is influenced by many factors such as the spindle speed, feed rate, depth of cut, geometry of cutting tool cutting conditions etc. The finished product with desired attributes of size, shape, 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. Surface roughness and material removal rate are the performance characteristics on the basis of which the machining parameters, including spindle speed, feed rate, depth of cut and material type are optimized in this dissertation work. The layout of the experiment is designed based on Taguchi's L_{16} orthogonal array and analysis of variance (ANOVA) is used to identify the effect of the machining parameters on individual responses. The S/N ratio is used to analyze the performance characteristics in CNC turning operation. The S/N ratio values are calculated by taking into consideration with the help of software Minitab 17 (trial version). Four levels of each machining parameters are used and experiments are done on MAXTURN PLUS, CNC lathe machine tool of MATAB using carbide insert tool. The results shows that optimum parameter for surface roughness is speed 1500 rpm (level 4), feed rate 0.1 mm/rev (level 1), depth of cut 1.0 mm (level 4) and material type EN47 (level 4). Whereas for material removal rate the optimum parameter is speed 1500 rpm (level 4), feed rate 0.19 mm/rev (level 4), depth of cut 1.0 mm (level 4) and material type EN8 (level 1). Further the ANOVA results shows that spindle speed and feed rate have statistically significant effect on surface roughness and in case of material removal rate depth of cut has statistically significant effect. A confirmation experiment is carried out to verify the optimal process parameter settings obtained during this study. The confirmation test results shows that the predicted values of surface roughness and material removal rate are in the acceptable zone with respect to the experimental values based on the optimized process parameters.

Key Words: Turning, ANOVA, S/N, MAXTURN PLUS CNC, MATLAB etc.

1. INTRODUCTION

Machining is the process of removing unwanted material from a work piece in the form of chips. If the work piece is metal, the process is often called metal cutting or metal removal. Metal cutting is one of the most significant manufacturing process in the area of metal removal (Chang and Smith, 1997). However, Black (1979) defined metal cutting as the removal of metal chips from a work piece in order to obtain a finish product with desired attributes of size, shape and surface roughness.

The process of metal cutting is complex because it has such a wide variety inputs. These variables are:

1. The machine tool selected to perform the process.
2. The cutting tool selected (geometry & material).
3. The properties and parameters of the work piece.
4. The cutting parameters selected (speed, feed & depth of cut).
5. The work piece holding devices or fixtures or jigs.

In all machining processes, the work piece is a shape that can entirely cover the final part shape. The objective is to cut away the excess material and obtain the final part. This cutting usually requires to be completed in several steps – in each step, the part is held in a fixture, and the exposed portion can be accessed by the tool to machine in that portion. Common fixtures include vice, clamps, 3-jaw or 4-jaw chucks, etc. Each position of holding the part is called a setup. One or more cutting operations may be performed, using one or more cutting tools, in each setup. To switch from one setup to the next, we must release the part from the previous fixture, change the fixture on the machine, clamp the part in the new position on the new fixture, set the coordinates of the machine tool with respect to the new location of the part, and finally start the machining operations for this setup. Therefore, setup changes are time-consuming and expensive, and so we should try to do the entire cutting process in a minimum number of setups.

In modern industry the goal is to manufacture low cost, high quality products in short time. Automated and flexible manufacturing systems were employed for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy and very low processing time. Turning was the most common method for cutting and especially for the finishing machined parts. Furthermore, in order to produce any product with desired quality by machining, cutting parameters should be selected properly (Chorng et. al., 2012). Metal cutting operations

Common metal cutting operations include:

1. sawing
2. shaping (or planing)
3. broaching
4. drilling, reaming, boring and tapping
5. grinding
6. milling, and
7. turning

1.1 Performance measures

In a turning operation, a number of methods are available for evaluating machining performance characteristics such as tool life, cutting force, surface roughness, material removal rate etc. Among the available machining performance characteristics surface roughness and material removal rate are considered for the present study.

1.2 Machining parameters in turning process

The three primary factors in any basic turning operation are spindle speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

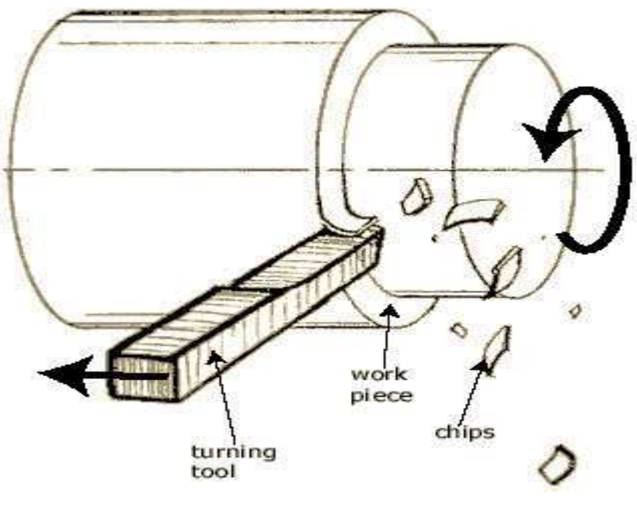

Figure 1.1: Machining parameters in turning process

1.3.1 Speed

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed.

$$v=\frac{\pi DN}{1000}\ \text{m/min} \qquad (1.1)$$

Here, v is the cutting speed in m/min; D is the initial diameter of the work piece in mm, and N is the spindle speed in rpm.

1.3.2 Feed

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the cutting speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$$F=f.N\text{mm/min}. \qquad (1.2)$$

Here, F is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in rpm.

1.3.3 Depth of cut

Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm.

$$DOC=\frac{D-d}{2}\text{mm} \qquad (1.3)$$

Here, D and d represent initial and final diameter (in mm) of the job respectively.

1.3 Factors influencing the surface roughness and material removal rate in turning operation

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

- Cutting speed
- Feed rate
- Depth of cut
- Cutting tool wears
- Use of cutting fluid

2. LITERATURE REVIEW

Cesarone (2001) shows that conducting an effective DOE requires review of literature regarding turning parameters and similar studies as it is important to understand the process in this type of study. Additionally, recent reviews of DOE studies by researchers and professionals are helpful in determining what aspects of this method work best.

Shivade et al. (2014) presented the single response optimization of turning parameters for Turning on EN8 Steel. Experiments are designed and conducted on conventional lathe machine based on Taguchi's L_9 orthogonal array design. This paper discusses an investigation into the use of Taguchi parameter Design optimize the surface roughness and tool tip temperature in turning operations using single point carbide cutting Tool. The analysis of variance (ANOVA) is employed to analyse the influence of process parameters during turning.

Ballal et al. (2013) presented the study of an application of Taguchi method for optimization of surface roughness and material removal rate in turning gray cast iron brake drum. Machining performance of a series of commercially available coated tungsten carbide inserts were investigated during turning of gray cast iron brake drum on CNC lathe. The inserts tested had a coating of TiCN and TiAlN respectively. For comparison, uncoated cemented tungsten carbide insert of K10 grade was also tested under the same cutting conditions. Taguchi analysis using ANOVA for 3 parameter, 3 level experimentation - full factorial (L_{27} array) were done with output response variables like surface roughness, material removal rate.

Govindan and Vipindas (2013) studied quality of machined surfaces in turning operation. The comprehensive experimentation and analysis was performed on Al 6061 material based on Taguchi L_9 orthogonal array. The commonly used parameters speed, feed and depth of cut were used for this assessment. The roughness values vary between 0.3 and 4.4 µm. A general linear model was employed to evaluate the parametric effects. It was observed that feed is the significant factor at 95% confidence level. Feed has the strongest influence on the quality of machined surfaces in CNC turning.

The literature survey depicts that a considerable amount of work has been carried out by number of investigators for modelling, simulation and parametric optimization of surface properties of the product in turning operation using different process parameters, different cutting tools and various cutting condition. But very few work had been carried out by considering material type of different grades of EN series steel as one of the input parameter. So, in this study different EN series steels namely EN8, EN24, EN31 and EN47 are considered.

3. METHODOLOGY:

In machining operations, the quality of the surface finish plays an important role for particularly turned work pieces. However, human operators or programmers normally inspects the surface according to their experiences or refer to machining handbooks. Optimization of turning parameters is usually a difficult work where the following aspects are important such as knowledge of machining and the specification of machine tool capabilities.

3.1Taguchi based design of experiments

Among the available methods, Taguchi's design is one of the most powerful design of experiments methods for analyzing of experiments. It is widely recognized in many fields particularly in the development of new products and processes in quality control. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi has empirically found that the two stage optimization procedure involving S/N ratios, indeed gives the parameter level combination, where the standard deviation is minimum, while keeping the mean on target .This implies that engineering systems behave in such a way that the manipulated production factors that can be divided into three categories:

(i). Control factors, which affect process variability as measured by the S/N ratio.

(ii). Signal factors, which do not influence the S/N ratio or process mean.

(iii). Factors, which do not affect the S/N ratio or process mean.

(1) Nominal-is-the-best:

$$S/N_T = 10.\log\left(\frac{\bar{y}}{s_y{}^2}\right) \quad (3.1)$$

(2) Larger-is-the-better (maximize):

$$S/N_L = -10.\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i{}^2}\right) \quad (3.2)$$

(3) Smaller-is-the-better (minimize):

$$S/N_s = -10.\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i{}^2\right) \quad (3.3)$$

Where$\bar{y}$, is the average of observed data, $s_y{}^2$ is the variance of y, n is the number of observations and y is the observed data. Notice that these S/N ratios are expressed on a decibel scale.

Taguchi method-based design of experiments involved following steps:

- Definition of the problem
- Identification of noise factors
- Selection of response variables
- Selection of control parameters and their levels

- Selection of the orthogonal array
- Conducting the matrix experiments (experimental procedure and set-ups)
- Analysis of the data and prediction of optimum level
- Confirmation experiment

4. EXPERIMENTATION and Result

4.1Design of Experiment

The design of experiments technique is a very powerful tool, which permits us to carry out the modelling and analysis of the influence of process variables on the response variables. The response variable is an unknown function of the process variables, which are known as design factors. In a turning operation, there are a large number of factors that can be considered as the machining parameters. But, the review of literature shows that the depth of cut (d, mm), spindle speed (N, rpm) and feed rate (f, mm/rev) are the most widespread machining parameters taken by the researchers. In the present study these are selected as design factors while other parameters have been assumed to be constant over the experimental domain.

Figure 4.1: MAXTURN + CNC lathe front view

Figure 4.2: CNC lathe setup

4.2 CNC lathe machine and its specifications:

All experiments have been carried out on MAXTURN PLUS, CNC Lathe machine tool of MTAB. MAXTURN PLUS is a numerically controlled machine tool used for machining parts in every industrial field, featuring high speed, high accuracy and high productivity. It performs operations using CNC programming and Siemens Controller Operation as shown in figure 4.1. The specifications of the CNC lathe machine is given below:

Type MAXTURN PLUS CN

Lathe, MTAB

Controller Siemens (Sinumeric 828D)

Power Supply 3Φ,415V AC, 50 Hz

Control Voltage 24V DC

Spindle Speed 6000 rpm (Max. Speed)

4.3 Cutting tool and its specification

The cutting tool used during the experimentation is shown in figure 4.3. With all its standard specification a tungsten carbide insert of VNMG160408 is employed for the machining operation of the present study. The designation of the cutting tool is explained as under:

Figure 4.3: Cutting tool insert

V: Turning Insert Shape for finishing operation

N: Turning Insert with 0°clearance angle

M: Turning Insert Tolerances like the tolerance in turning insert length, height etc.

G: Turning insert with Cylindrical hole and Double-Sided Chip breaker

16: Turning Insert Size i.e. cutting edge length of the turning insert.

04: Turning Insert Thickness

08: Turning Insert Nose Radius

4.4 Work piece material

The work piece material used is four different EN grade

Table 4.1: Chemical composition of EN8, EN24, EN31 and EN47

Carbon Steel	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%V	%Al
EN8	0.43	0.20	0.79	0.024	0.020	-	-	-	-	0.56
EN24	0.45	0.22	0.57	0.040	0.040	1.5	0.30	1.55	-	-
EN31	1.01	0.20	0.33	0.020	0.010	1.36	-	-	-	-
EN47	0.49	0.24	0.66	0.040	0.033	0.93	-	-	0.193	-

of steels i.e. EN8, EN24, EN31 and EN47 using cutting fluid Water-soluble mineral oil (trade name: 68 Pentagon cutting oil). The chemical composition and mechanical properties of the work piece materials are shown in table 4.1, table 4.2, table 4.3, table 4.4 and table 4.5 respectively. It is available in material hand book. It is a bar of Φ34 × 150 mm.

Table 4.2: Mechanical properties of EN8

S.No.	Mechanical Property	Range
1	Max Stress	700-850 N/mm^2
2	0.2% Proof Stress	450 N/mm^2
3	Yield Stress	465 N/mm^2
4	Elongation	16%
5	Density	7.8 gm/cc
6	Hardness	201-255 Brinell

Table 4.3: Mechanical properties of EN24

S.No.	Mechanical Property	Range
1	Max Stress	850-1000 N/mm^2
2	Tensile Strength	680 N/mm^2
3	Yield Stress	650 N/mm^2
4	Elongation	13%
5	Density	7.85 gm/cc
6	Hardness	248-302 Brinell

Table 4.4: Mechanical properties of EN31

S.No.	Mechanical Property	Range
1	Modulus of Elasticity	215000 N/mm^2
2	Tensile Strength	750 N/mm^2
3	Yield Stress	450 N/mm^2
4	Elongation	30%
5	Density	7.8 gm/cc
6	Hardness	63 Brinell

Table 4.5: Mechanical properties of EN47

S.No.	Mechanical Property	Range
1	Modulus of Elasticity	200000 N/mm^2
2	Tensile Strength	650-880 N/mm^2
3	Yield Stress	350-550 N/mm^2
4	Elongation	19%
5	Density	7.7 gm/cc
6	Hardness	275 Brinell

4.5 Process variables and their limits

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L_{16} Orthogonal Array (OA) design have been selected. Considering the literature review and the available machine settings following process parameters were selected for the present work:

(i) Cutting speed
(ii) Feed
(iii) Depth of cut, and
(iv) Work material

Table 4.6: Process variables and their limits

Parameter	Symbol	Unit	Level 1	Level 2	Level 3	Level 4
Speed	A	rpm	900	1100	1300	1500
Feed	B	mm/rev	0.1	0.13	0.16	0.19
Depth of cut	C	mm	0.25	0.5	0.75	1.0
Work Material	D		EN8	EN24	EN31	EN47

Table 4.7: Taguchi's L_{16} orthogonal array (OA) design

Experiment	Spindle Speed (A)	Feed Rate (B)	Depth of Cut (C)	Material Type (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

4.5.1 Response parameters

The response parameters considered in this study are surface roughness and material removal rate.

4.5.1.1 Surface roughness

The terms surface roughness and surface finish are widely used in manufacturing sector to quantify the smoothness of the machined surface. A machined surface is a result of geometric and kinematics reproduction of the tool point shape and trajectory.

Surface roughness of machined parts is described by several parameters. Some of the generally used parameters of surface roughness specification are listed as follows:

- Root-mean-square roughness (R_q)
- Maximum peak-to-valley roughness height (Ry or Rmax)
- Average roughness (R_a)

4.5.2 Material removal rate (MRR)

The material removal rate (MRR) can be defined as the volume of material removed divided by the machining time. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the work piece. The MRR is also calculated by determining the difference of weight before and after machining. We use both these methods (eq. 4.1 and eq. 4.2) for calculating MRR.

$$MRR = \frac{\frac{\pi}{4} * (D^2 - d^2) * L}{T_c} \text{ (mm}^3\text{/sec)} \qquad (4.1)$$

where,

D is initial diameter of work piece in mm,

d is final diameter of work piece in mm,

L is machining length in mm, and

T_c is machining time in sec.

The machining length (L) is held to be constant i.e. L = 50mm.

So, higher the material removal rate means lesser the machining time.

The MRR is also calculated by another formula using the difference of weight before and after machining as,

$$MRR = \frac{\text{Initial weigth of work piece(gm)} - \text{final weigth of work piece(gm)}}{\text{density}\left(\frac{gm}{mm^3}\right) * \text{machining time (sec)}} \ (mm^3/sec) \quad (4.2)$$

4.6 Part program used for turning operation:

NC/MPF/STRAIGHT TURNING

N5 WORKPIECE („,”CYLINDER”,192,0,-150,-50,35)

N10 G71G95

N15 G75X0Z0

N20 T=”FINISHING_TOOL” D1

N25 LIMS=900

N30 G96S900M03

N35 M08

N40 G00X35Z10

N45 G01Z2F0.1

N50 CYCLE 62 (“SURF”,0,)

N55 CYCLE 952 ("OD",,"",2101321,0.01,0,0,0.5,0.1,0.1,0.1,0.1,0.1,0.01,1,30, 2,,,,,2,2,,,0,1,,0,12,1101010,1,0)

Figure 4.4: Drawing of work piece

N60 M09

N65 G75X0Z0

N70 M05

N75 M30

NC/SPF/SURF.SPF

N5 G01X34Z0

N10 G01Z-50

N15 M17

4.7 EXPERIMENTAL RESULTS

4.7.1 Determination of optimal settings of process parameters

The surface roughness (Ra) and material removal rate (MRR) for different combinations of turning parameters of 16 experimental runs are listed in Table 4.7. The following sequential steps were adopted to determine the optimal combination of the turning process parameters based on Taguchi’s optimization technique:

a) S/N ratios for the experimental data are calculated.
b) The main effects plots and S/N ratios plots are drawn
c) ANOVA is carried out to determine the significant contribution of the factors.
d) Validation of ANOVA results is performed.
e) A confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

As far as machining quality characteristics is concerned, the lower surface roughness and the higher material removal rate (MRR) are indications of optimal performance. The S/N ratios of the surface roughness and material removal rate (MRR) for 16 experimental runs calculated using eq. (4.1) and eq. (4.2) are listed in Table 4.8 and Table 4.9 respectively.

Table 4.8: Experimental design using L_{16} orthogonal array for surface roughness (Ra)

Experiment No.	Spindle Speed (rpm)	Feed Rate (mm/rev.)	Depth of Cut (mm)	Material Type	Surface roughness Ra (μm)	S/N Ratio (dB)
1	900	0.1	0.25	EN8	1.25	-1.93820
2	900	0.13	0.5	EN24	1.95	-5.80069
3	900	0.16	0.75	EN31	1.59	-4.02794
4	900	0.19	1.0	EN47	1.81	-5.15357
5	1100	0.1	0.5	EN31	0.52	5.67993
6	1100	0.13	0.25	EN47	0.84	1.51441
7	1100	0.16	1.0	EN8	1.10	-0.82785
8	1100	0.19	0.75	EN24	1.63	-4.24375
9	1300	0.1	0.75	EN47	0.54	5.35212
10	1300	0.13	1.0	EN31	0.89	1.01220
11	1300	0.16	0.25	EN24	1.18	-1.43764
12	1300	0.19	0.5	EN8	1.32	-2.41148
13	1500	0.1	0.25	EN24	0.49	6.19608
14	1500	0.13	0.5	EN8	1.01	-0.08643
15	1500	0.16	1.0	EN47	1.03	-0.25674
16	1500	0.19	0.75	EN31	1.30	-2.27887

4.7.2 Main effects plots

The data is further analyzed with the help of main effects plots using software package Minitab 17. The plots show the variation of individual response with three machining parameters; spindle speed, feed rate, depth of cut and material type separately. In the plots, the x-axis indicates the value of each machining parameters and material type at four level and y-axis indicates the response value (surface roughness). The main effects plots are used to determine the optimal design conditions to obtain the low surface roughness.

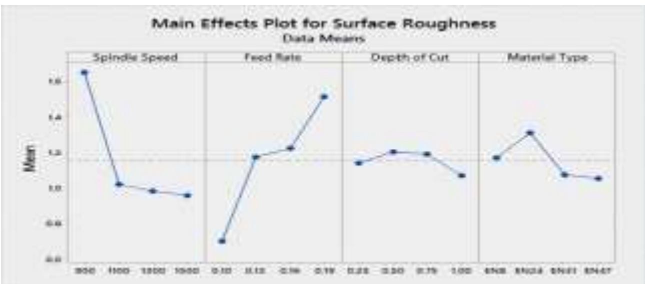

Figure 4.5: Main effects plot for surface roughness

Level	Spindle Speed	Feed Rate	Depth of Cut	Material Type
1	1.6500	0.7000	1.1425	1.1700
2	1.0225	1.1725	1.2050	1.3125
3	0.9825	1.2250	1.1925	1.0750
4	0.9575	1.5150	1.0725	1.0550
Delta	0.6925	0.8150	0.1325	0.2575
Rank	2	1	4	3

Table 4.9: Response table for means

4.7.3 Signal-to-Noise (S/N) ratio plots

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the largest value. Figure 5.2, shows the predicted optimal parameter setting for minimum surface roughness at spindle speed 1500 rpm (level 4), feed rate 0.1 mm/rev (level 1) and depth of cut 1.0 mm (level 4) and material type EN47 (level 4).

Figure 4.6: S/N ratios plot for surface roughness

The advantage of S/N ratios plot is that it also provides the significant rank's hierarchy of machining (input) parameters. As it can be clearly observed from table 4.10 that feed rate having (rank 1) has the greatest effect on the response parameter i.e. surface roughness, followed by spindle speed (rank 2), material type (rank 3) and lastly depth of cut (rank 4).

Level	Spindle Speed	Feed Rate	Depth of Cut	Material Type
1	-4.23010	3.82248	-1.03507	-1.31599
2	0.53069	-0.84013	-0.69725	-1.32150
3	0.62880	-1.63755	-0.75150	0.09633

4	0.89351	-3.52192	0.30671	0.36406
Delta	5.12361	7.34440	1.34179	1.68556
Rank	2	1	4	3

Table 4.10: Response table of S/N ratios for surface roughness

4.8 Confirmation experiment:

Based on the S/N ratios and ANOVA analyses, the optimal levels of all the control factors' combination are identified. As mentioned before the optimum setting of parameters for surface roughness is A4B1C4D4 and for material removal rate is A4B4C4D1. A confirmation experiment is the final step of a design of experiment. Its purpose is to verify that the optimum conditions suggested by the matrix experiment do indeed give the projected improvement. The confirmation experiment is performed by conducting a test with optimal settings of the factors and levels previously evaluated. The predicted value of S/N ratio at optimum level (η_0) is calculated by formula (4.3).

$$\eta_0 = \eta_m +)\sum_{i=1}^{j}(\eta_i - \eta_m) \qquad (4.3)$$

Where, j is the number of factors and η_m is the mean value of S/N ratios in all experimental runs, η_i are the S/N ratios corresponding to optimum factor levels (Ross 1996, Dubey et al 2007).

5.4.1 S/N ratio calculation at optimum level

For surface roughness:

$$\eta_0 = \eta_m + (\eta_{A4} - \eta_m) + (\eta_{B1} - \eta_m) + (\eta_{C4} - \eta_m) + (\eta_{D4} - \eta_m) \quad (4.4)$$

Where,

η_0 is optimum S/N ratio,

η_m is the overall mean of S/N values,

η_{A4} is the average value of S/N at fourth level of spindle speed (1500 rpm).

η_{B1} is the average value of S/N at the first level of feed rate (0.1 mm/rev.).

η_{C4} is the average value of S/N at fourth level of depth of cut (1 mm).

η_{D4} is the average value of S/N at fourth level of material type (EN47).

From table 5.3, we have

η_m= -0.54427 η_{A4}= 0.89351 η_{B1} = 3.82248 η_{C4} = 0.30671

η_{D4} = 0.36406

η_0 = -0.54427 + (0.89351+0.54427) + (3.82248+0.54427) + (0.30671+0.54427) + (0.36406+0.54427)

η_0 = 7.01957 (4.5)

If the optimum S/N ratio is known the value of surface roughness can be determined by equation 3.3. The procedure is to back-transform S/N ratio to find expected performance value (Roy 2001, Savaşkan 2003).

When the optimum S/N ratio value obtained in equation (4.5) is put into equation (3.3), the expected performance value for surface roughness comes out to be

$$S/N_s = -10.\log(\frac{1}{n}\sum_{i=1}^{n} y_i 2)$$

7.01957 = -10 log y^2

7.01957 = -20 log y

Log y = -0.3509785

y = $10^{-0.3509785}$

y = 0.4456

For material removal rate the same procedure is followed as that of surface roughness for calculating the optimum S/N ratio and then the expected performance value.

Table 4.11: Results of confirmation experiment

	Optimal cutting parameter	
	Prediction	Experimental
Level	A4B1C4D4	A4B1C4D4
Surface Roughness (µm)	0.4456	0.4857
S/N ratio (dB)	7.01957	6.27263
Level	A4B4C4D1	A4B4C4D1
Material Removal Rate (mm^3/sec)	246.959	259.250
S/N ratio (dB)	47.8525	48.27437

A4 (Spindle Speed=1500 rpm); B1 (Feed rate=0.1mm/rev.); C4 (Depth of cut= 1mm);

D4 (Material Type= EN47); B4 (Feed rate= 0.19mm/rev.); D1 (Material Type=EN8)

The confirmation test is done to check whether the predicted results are in acceptable zone with respect to the experimental results or not based on the optimised process parameters. Thus, analysing the results of confirmation test, it can be concluded that the predicted values of surface roughness and material removal rate seems to have been in good agreement with the experimental values.

4.9 Conclusions

In this study, an attempt has been made to apply the parameter design of the Taguchi method in the optimization of turning operations. The following conclusions can be drawn based on the results of this study:

- Taguchi's robust orthogonal array design method is suitable to analyse the surface roughness and material removal rate during turning operation.
- It is found that the parameter design of the Taguchi method provides a simple, systematic and efficient methodology for the optimization of the machining parameters.
- In turning for minimum surface roughness, use of higher spindle speed (1500 rpm), lower feed rate (0.1 mm/rev), higher depth of cut (1.0 mm) and EN grade material (EN47) i.e. A4B1C4D4, are recommended to obtain lower surface roughness.
- The experimental results show that the effect of spindle speed on surface roughness is about (48.17%) and feed rate is (42.54%) respectively. These are the main parameters among the four controllable factors (spindle speed, feed rate, depth of cut and material type) that influence the surface roughness.
- In turning for maximum material removal rate, use of higher spindle speed (1500 rpm), higher feed rate (0.19 mm/rev), higher depth of cut (1.0 mm) and EN grade material (EN8) i.e. A4B4C4D1, are recommended to obtain a higher material removal rate for the specific test range.
- The experimental results show that the depth of cut (78.31%) and feed rate (12.13%) are the main parameters among the four controllable factors (spindle speed, feed rate, depth of cut and material type) that influence the material removal rate as a response parameter.
- The confirmation test results shown in table 4.11 shows that the predicted values of surface roughness and material removal rate are in the acceptable zone with respect to the experimental values based on the optimised process parameters.

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