



Parametric optimization of cutting in turning operation using Taguchi method

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Abstract

A common method to manufacture parts to a specific dimension involves the removal of excess material by machining operation with the help of cutting tool. Turning process is the one of the methods to remove material from cylindrical and non-cylindrical parts. In any machining process, it is most important to determine the optimal settings of machining parameters aiming at reduction of production costs and achieving the desired product quality. Different experiments are done by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Operating range is found by experimenting with top spindle speed and taking the lower levels of other parameters. Every day scientists are developing new materials and for each new material, we need economical and efficient machining. It is also predicted that Taguchi method is a good method for optimization of various machining parameters as it reduces the number of experiments. In this work the relation between change in hardness caused on the material surface due the turning operation with respect to different machining parameters like spindle speed, feed and depth of cut have been investigated. Taguchi method has been employed to plan the experiment where the material used is aluminium. The main effects have been calculated and percentage contribution of various process parameters affecting hardness also determined.

Keywords: turning machine, spindle speed, feed, depth of cut, Taguchi method etc.

1. Introduction

Machining is the most wide spread metal machining process in mechanical manufacturing industry. The goal of changing the geometry of raw material in order to form mechanical parts can be met by putting material together. Conventional machining is the one of the most important material method. Machining is a part of the manufacturing all most all metals products. In order to perform cutting operations, different machining tools such as lathes, drilling machine, horizontal and vertical milling machines etc. are utilizing. Out of this machining process, turning still remains most important operation used to shape metal, because in turning the condition of Operation are most varied. Increasing productivity and reducing manufacturing cost has always been the primary object of successful business. In turning, higher values of cutting parameter offered opportunities for increasing productivity but it also involves greater risk of deterioration in surface quality and tool life. Turning operation is very important material removal process in modern industry. The study on the influence of hardness during machining has been going back to change. Turning is a form of machining or a material removal process which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. The work piece is a piece of re-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine. The cutting tool feeds into the rotating work piece and cuts away material in the form of

small chips to create the desire shape. In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool material, tool size, and more.

2. Literature review

Many eminent researchers from India such as, Saravanan R Baskar N., Asokan P., and Prabhakaran, showed significant improvement in conventional Turning process optimization by using various non conventional optimization techniques. They compared their results with the results obtained from hand books. The goal of optimization in all the cases is to determine the minimum surface roughness by considering various constraints and input variables. Some researchers tried various combinations of cutting process parameters and non-traditional optimization techniques namely PSO, artificial be colony and simulated annealing are utilized efficiently to optimize various parameters. Oktem and Erzurumlu observed closeness in the results between experimental and predicted values in turning process. They used neural network and genetic algorithm. Azlonzain, Haron and sharif observed the effect of different parameter like cutting speed, feed and rake angle in surface roughness. They compared the result of regression modeling and genetic algorithm. I.N. Tansela, *et al.* have taken three parameters namely cutting speed, feed rate and radial depth of cut for turning process and applied ANN. They obtained good agreement between predicted and actual values. Response surface methodology is another technique applied by researchers for developing predictive modeling for

surface roughness. Onwubolu & G.C however used the Tribes optimization for determination of cutting parameters in turning process to obtain better results for a particular context. From the review of various papers, the optimization on turning process has started only in recent past. Most of the researchers in were using soft computing based optimization methods and found good results. The literature related to turning optimization is mainly concerned with minimization of surface roughness.

3. Materials and methodology

3.1 Work Piece Material

An aluminium rod is used for the machining operation. After iron, aluminium is now the second most widely used metal in the world. This is because aluminium has a unique combination of attractive properties. Low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminium most important Properties. Aluminium is also very easy to recycle. Aluminium alloys commonly have tensile strengths of between 70 and 700 MPa. The range for alloys used in extrusion is 150 – 300 MPa. Unlike most steel grades, aluminium does not become brittle at low temperatures.

3.2 Tool material

High-speed steel (HSS)

It is used as the cutting tool material. It is a subset of tool steels, commonly used in tool bits and cutting tools. It is often used in power-saw blades and drill bits. It is superior to the

older high-carbon steel tools used extensively through the 1940s in that it can withstand higher temperatures without losing its temper (hardness). This property allows HSS to cut faster than high carbon steel, hence the name high-speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above HRC60) and abrasion resistance (generally linked to tungsten and vanadium content often used in HSS) compared with common carbon and tool steels.

3.3 Machining Process

The experiments were conducted as per the orthogonal array and the spindle speed, depth of cut, feed is measured and the surface roughness is measured with the help of stylus type Profilometers. A Profilometer is a device used to measure the roughness of a surface. There are two classes of Profilometers: contact and non-contact. Stylus Profilometer are the industry standard method of measuring surface finish. They have been in use for over sixty years. Originally they were used to provide an amplified graph of the surface profile and a simple indication of some “average” parameter such as Ra. This parameter was determined by means of a simple electronic circuit and suitable meter. The lateral resolution is dependent on probe size (radius), speed, scan length, and the force applied. A stylus with a diamond tip is run over a sample of a material. The stylus records the groves as a wave pattern and sends the information back to a computer. This computer can use the wave to directly model the surface as the stylus moves. By the time the process is done, the system will have an accurate model of every location measured.

3.4 Experimental details

Table 1: Observation Table

Machining Parameter			Turning Process	
Trail No.	Cutting Speed 'V' (m/min)	Feed 'f' (mm/rev)	Depth of cut (mm)	Surface Roughness 'Ra' (μ m)
1	35	0.2	1.5	0.72
2	25	0.2	1	0.85
3	25	0.15	1	0.56
4	35	0.1	1	0.63
5	25	0.1	1	0.49
6	35	0.15	1	0.64
7	35	0.2	1.25	0.79
8	45	0.15	1	0.56
9	45	0.1	1	0.67
10	25	0.15	1.25	0.59
11	25	0.2	1.5	0.27
12	35	0.1	1.25	0.23
13	25	0.1	1.25	0.37
14	25	0.2	1.25	0.43
15	45	0.2	1.25	0.32
16	45	0.1	1.25	0.44
17	45	0.2	1	0.22
18	25	0.15	1.5	0.33
19	25	0.1	1.5	0.25
20	35	0.2	1	0.33

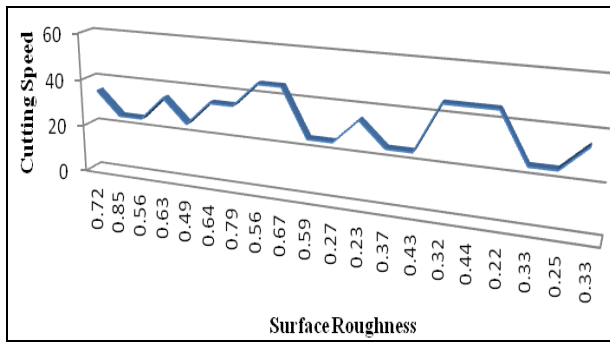


Fig 1: Cutting speed with surface roughness

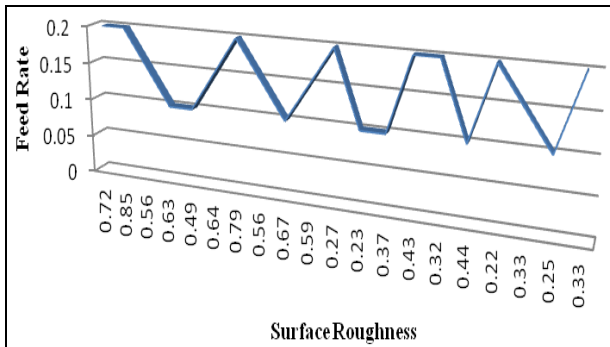


Fig 2: Feed with Surface Roughness

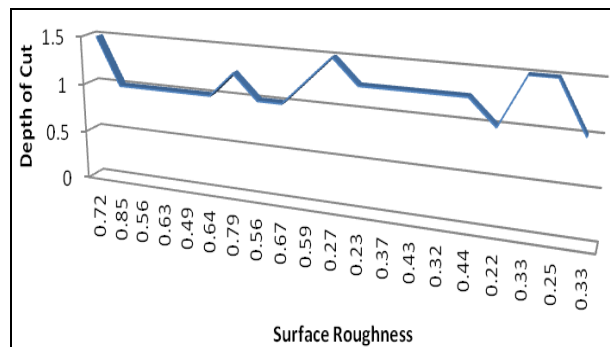


Fig 3: Depth of cut versus surface roughness

3.5 Taguchi Process Stages

Taguchi realized that the best opportunity to eliminate variation is during the design of a product and its manufacturing process. The process has three stages:

- System design
- Parameter design
- Tolerance design

Approach to the Experimental Design

In accordance with the steps that are involved in Taguchi’s Method, a series of experiments are to be conducted. Here, facing operation on mild steel components using a lathe has been carried out as a case study. The procedure is given below:

a) Identification of Main Function and its side effects

Before proceeding on to further steps, it is necessary to list

down all the factors that are going to affect or influence the facing process and from those factors one has to identify the control and noise factors. The “Factors” that affect facing operation on a lathe machine are listed in the table 3.

Table 3: Factors that affect Turning Operation

Control Factors	Noise Factors
Cutting speed	Vibration
Depth of cut	Raw material variation
Feed rate	Machine Condition
Nose radius	Temperature
Coolant	Operator Skill

After listing the control and the noise factors, decisions on the factors that significantly affect the performance will have to be ascertained and only those factors must be taken in to consideration in constructing the matrix for experimentation. All other factors are considered as Noise Factors.

b) Identifying the testing conditions and quality

Table 4: Characteristics to be observed

Quality Characteristic	Surface finish
Work piece material	Aluminium
Cutting tool	Tungsten Carbide Tipped Tool
Operating Machine	Lathe machine
Testing Equipment	Portable surface tester

c) Identify the Objective Function

S/N Ratio for this function

$$SN_i = -10 \log \frac{1}{N_i} \sum_{u=1}^{N_i} \frac{1}{y_u^2}$$

Where, n= Sample Size, and y= Surface Roughness in that run

d) Identifying the Control Factors and their levels

The factors and their levels were decided for conducting the experiment, based on a “brain storming session”. The factors and their levels are shown in table 4.

Table 4: Selected Factors and their Levels

Factor	Levels		
	1	2	3
Cutting speed(v, rpm)	25	35	45
Depth of cut(t, mm)	1	1.25	1.5
Feed rate(f, mm/min)	0.1	0.15	0.2

e) Selection of Orthogonal Array

To select an appropriate orthogonal array for conducting the experiments, the degrees of freedom are to be computed. The same is given below: Degrees of Freedom: 1 for Mean Value and 8= (2x4),two each for the remaining factors Total Degrees of Freedom: 9. the most suitable orthogonal array for experimentation is L9 array as shown in Table 5. Therefore, a total nine experiments are to be carried out.

Table 5: Orthogonal Array (OA) L9

Experiment No.	Control factors		
	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	1
9	3	3	3

f) Conducting the Matrix Experiment

In accordance with the above OA, experiments were conducted with their factors and their levels as mentioned in table 4. The experimental layout with the selected values of the factors is shown in Table 6. Each of the above 9 experiments were conducted 5 times (45 experiments in all) to account for the variations that may occur due to the noise factors.

Table 6: OA with Control Factors

Experiment No.	Control factors		
	1	2	3
1	25	1.25	0.1
2	25	1	0.15
3	25	1.5	0.2
4	35	1.25	0.2
5	35	1	0.1
6	35	1.5	0.15
7	45	1.25	0.15
8	45	1	0.1
9	45	1.5	0.2

g) Examination of Data

The following are the experimental results of the work carried out. Since the objective function (Surface Finish) is smaller-the-better type of control function, was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated as shown in Table 7.

Table 7: Tabulated S/N ratios

Experiment No.	S/N Ratio
1	-7.9702
2	-9.2568
3	-10.4539
4	-10.9196
5	-11.0971
6	-12.101
7	-9.2385
8	-10.4642
9	-9.2941

The S/N ratio for the individual control factors are calculated as given below:

$Ss1 = (\eta_1 + \eta_2 + \eta_3)$, $Ss2 = (\eta_4 + \eta_5 + \eta_6)$ & $Ss3 = (\eta_7 + \eta_8 + \eta_9)$
 $Sf1 = (\eta_1 + \eta_4 + \eta_7)$, $Sf2 = (\eta_2 + \eta_5 + \eta_8)$ & $Sf3 = (\eta_3 + \eta_6 + \eta_9)$
 $St1 = (\eta_1 + \eta_5 + \eta_9)$, $St2 = (\eta_2 + \eta_6 + \eta_7)$ & $St3 =$

$(\eta_3 + \eta_4 + \eta_8)$

Average S/N ratio corresponding to Cutting Speed at level 1 = $Ss1/3$ Average S/N ratio corresponding to Cutting Speed at level 2 = $Ss2/3$ Average S/N ratio corresponding to Cutting Speed at level 3 = $Ss3/3$ j is the corresponding level each factor. Similarly Sfj and Stj are calculated for feed and depth of cut. The average of the signal to noise ratios is shown in table 8 Similarly S/N ratios can be calculated for other factors.

Table 8: Average S/N Ratio for each factor

Level	Speed		Feed		Depth of cut	
	Sum	Avg. S/N ratio	Sum	Avg. S/N ratio	Sum	Avg. S/N ratio
1	-27.68	-9.22	-28.36	-9.39	-28.12	-9.45
2	-34.11	-11.37	-30.59	-10.27	-30.81	-10.21
3	-28.99	-9.68	-31.83	-10.61	-31.84	-10.65

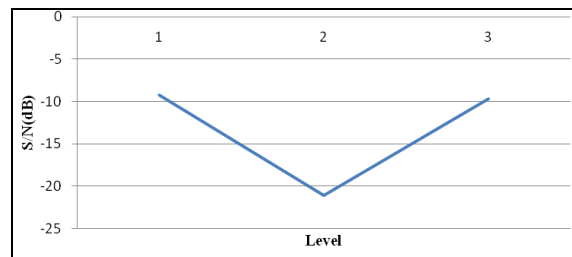


Fig 6: Plot of Speed

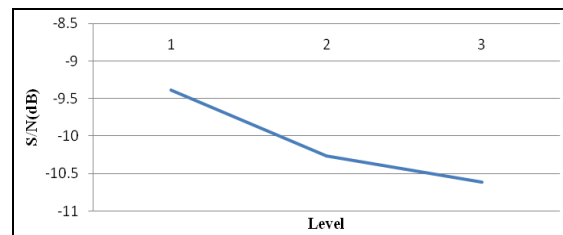


Fig 7: Plot of Feed rate

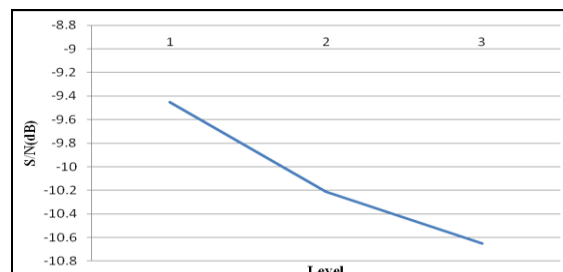


Fig 8: Plot of Depth of cut

h) Anova & Its Significance

Table 9 and Table 10 shows that the result of the ANOVA analysis for the surface roughness of turning and facing process respectively. This analysis was carried out for a significance level of $\alpha=0.05$, i.e. for confidence level of 95%. Tables [9-10] the Probability level that is the realized significance levels, associated with the F-tests for each source of variation. The sources with a Probability level less than 0.05 are considered to have a statistically significant contribution to the performance measures. Also last column of the tables show the percentage of contribution of each source to the total variation indicating the degree of influence on the

result. Table 9 shows that none of the factors were statistically significance with variation surface roughness. It can observe that the factor 'f' (33.74%) alone have significance on the surface roughness generation in the workpiece. From the Table 9 none of the factors having either statistical or physical significance on the flank wear obtained. Notice that the error associated in the ANOVA analysis for the surface roughness was 25.79% (turning) and 13.21% (facing) and for the flank wear was approximately 9.98 % (turning) and 31.8% (facing). If the error percentage was greater amount the linear model developed by using factor and their interactions may not give precise prediction results.

Table 9

Source	Sum Of Squares	Mean Square	F-Ratio	Probai Lity level	% of contribution
V	0.07061	0.0353	1.1	0.379	7.08
F	0.00501	0.0025	0.08	0.926	0.5
A	0.03645	0.01823	0.57	0.589	3.65
vxf	0.14395	0.03599	1.12	0.412	14.43
vxa	0.3279	0.08198	2.55	0.121	32.88
fxa	0.15617	0.03904	1.21	0.376	15.66
Error	0.25721	0.03215			25.79
Total 100	0.9973				100

i) Comparison of full factorial analysis with Taguchi parameter design

It is evident from the results of the full factorial analysis shown in Table 3, the best surface finish characteristics obtained were at 35 m/min, 1.25 mm depth of cut and 0.15 mm/rev feed rate. From Taguchi parameter design the optimum parameter levels obtained were also the same (see Table 10). Thus, it can be noted that Taguchi parameter design will also give accurate results with lesser number of experiments to be performed.

Table 10: Optimum values of factors and their levels

Parameters	Optimum value
Cutting speed(m/min)	35
Feed(mm/rev)	0.15
Depth of cut(mm)	1.25

4. Results and Conclusion

Cutting Speed

The harder the work material, the slower the cutting speed. The softer the work material the faster the recommended cutting speed.

The harder the cutting tool material, the faster the cutting speed. The softer the cutting tool material the slower the recommended cutting speed.

If the cutting speed is too slow than a lot of time is wasted during the machine process but if the cutting is too fast than also time is wasted in replacing or regrinding the cutters so the process should be carried out with an optimum cutting speed.

4.1 Feed

The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in inches per minute (IPM). As the feed increases the cutting force also increases but in accordance with this the tool life

decreases. If the feed is too slow than time is wasted and the cutter also chatters but if the cutter speed is too fast than than the cutter teeth can broke so the process should be carried out with a optimum value of feed.

4.2 Depth of Cut

The depth of the tool along its axis in the work piece as it makes a cut. As the depth of cut increases feed rate increases the load on tool increases and the combined effect of this is that the tool life decreases. There are several shallow cuts that waste time so this should be eliminated.

5. References

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