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EVALUATION AND OPTIMIZATION OF CUTTING PARAMETERS, FOR TURNING OF EN-8 STEEL: A TAGUCHI APPROACH

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ABSTRACT

The surface finish is one of the prime necessities of clients, for machine parts. This investigation concentrates on improving turning parameters in view of Taguchi technique, to limit surface harshness. Tests have been directed utilizing the L27 orthogonal array in a lathe machine, hard turning of EN-8 steel, utilizing carbide tool in dry condition. The statistical methods of S/N ratio- 'smaller is better'- and the analysis of variance (ANOVA) were applied, to investigate the effects on spindle speed, feed rate and depth of cut on surface roughness. The depth of cut was recognized as the most influential process parameter for minimum surface roughness.

KEYWORDS: ANOVA, EN-8, Surface Roughness, Taguchi Methods, Turning Machining

INTRODUCTION

Recently, hard turning, which utilizes a solitary point cutting tool, has swapped grinding to some degree for such applications. For the fruitful execution of hard turning, choice of appropriate cutting parameters for a given cutting tool; work-piece material and machine device are imperative strides. [1]. Hard turning is a procedure over which work pieces whose hardness extends in the vicinity of 50 and 70 HRC are machined by utilizing a solitary point cutting tool which have high hardness and are wear resistant. The hard turning displays an exceptional conduct, which is not quite the same as traditional turning operations. The use of hard turning innovation can be enhanced by using propelled advancement calculations, which causes makers to settle on instructing choices within the sight of different targets that should be fulfilled [2,3]. As EN-8 steels have wide varieties of application not only for forging and casting connecting rods, axle shafts and crank shafts, but also used for low cost die material in tool [4]. Significant advances have been seen in cutting tools and machine tools in recent years. Cutting parameters are to be determined by the hardness of materials and the unpleasantness of the surface of a work piece. The points of interest in machining materials with higher hardness are diminishing machining costs, sparing time, enhancing surface quality, and disposing of deformations in parts caused by temperature [5, 6]. Evolutionary based optimization technique of artificial bee colony algorithm for selecting the optimal cutting parameters in multi-pass turning operations is compared with previously published result [7]. The optimal cutting parameters during turning process using genetic algorithm for reducing the production cost and time is determined [8]. The turning process in EN31 steel alloy using tungsten carbide inserts is carried out by varying the cutting parameters, namely feed rate, depth of cut, and lubricant temperature to observe the effects of surface finis [9]. An experimental study of hard turning of AISI 52100 bearing steel, with CBN tool by using response surface methodology (RSM) is conducted to find the relationship between process parameters and performance characteristics. The outcomes demonstrate that the cutting rate shows the most extreme impact on abrasive tool wear and depth of cut influences the cutting forces emphatically [10]. Experiments have been designed to study the effect of turning parameters such as cooling condition, cutting speed, feed rate and depth of cut on arithmetic average roughness (Ra) and average maximum height of the profile (Rz) by turning of AISI 1050 steel .The mathematical model for surface roughness has been determined using response surface methodology and it has been concluded that feed is the most effective parameter on the surface roughness [11]. Because of the complex tool designs/cutting states of metal cutting operations and some obscure components and stresses, hypothetical cutting force was neglected in calculations to create exact outcomes. Along these lines, test estimation of the cutting forces wound up plainly unavoidable [12]. There have been many investigations concerning the impact of cutting parameters, for example, speed, feed, depth of cut, and so forth and tool geometry on cutting forces and surface roughness while machining distinctive materials [13-16]. A force expectation to complete the process of machining of EN31 steel utilizing sharpen edge uncoated CBN instrument has been developed and the forecasts of the developed models were contrasted and the deliberate drive and surface roughness esteems. The good scope of the machining parameter esteems is proposed for vitality proficient machining [17]. The effects of edge preparation of the cutting tool (round/hone edge and T-land/chamfer edge) on cutting forces using finite elemental analysis in orthogonal machining have been studied [18]. The impact of speed and feed rate on surface roughness and tool life utilizing three-level factorial outline on machining of solidified 100Cr6 bearing steel utilizing earthenware and CBN tool have examined [19]. In the present work, turning experiments were conducted on a precision lathe with carbide cutting tools for the machining of EN8 steel. The L27 orthogonal array based on design of experiments were applied to plan the experiments, by selecting three controlling factors, namely, the Spindle speed (S_s), feed rate (F) and depth of cut (D_c). The Taguchi analysis is applied to examine how these cutting factors influence the surface roughness (Ra). An optimal parameter combination was then obtained using the experimental results. Furthermore, conceptual S/N ratio approach and analysis of variance (ANOVA) were also carried out to examine the most significant factors for the surface roughness in the turning process.

TAGUCHI METHOD

Taguchi technique was developed by, Dr. Genichi Taguchi of Japan. Taguchi techniques for test configuration give a basic, proficient and deliberate approach, for the advancement of exploratory plans, for executional quality and cost. It has been demonstrated, as an effective method in many assembling circumstances. The conventional exploratory outline strategies, concentrate on the normal item or process execution attributes. But the Taguchi strategy focuses on the impact of minor departure, from the item or process quality attributes, instead of its midpoints i.e.; the Taguchi's approach makes the item or process execution harsh, to a variety of uncontrolled signal or noise variables. Taguchi prescribes that; this should be possible by the correct design parameters, amidst the 'parameter design' period, of disconnected quality control. He outlined certain standard orthogonal arrays (OAs), by which synchronous and the autonomous assessment of at least two parameters of their capacity, to influence the fluctuation of a specific item or process. Trademark should be awarded in the basic tests.

Signal to Noise (S/N) Ratio

Quality can be evaluated to the item's reaction, to noise and signal factors. The perfect item will just react to the administrator's signs and will be unaffected by arbitrary noise factors. Along these lines, the objective of our quality change exertion can be expressed as, endeavoring to augment the signal-to-noise (S/N) proportion, for the separate item.

The signal-to-noise (S/N) proportions, portrayed in the accompanying sections have been proposed by Taguchi (1987). This S/N ratio can be registered with the Taguchi robust design alternatives, in the design module. You can compute these S/N ratios for any data with MINITAB 17, STATISTICA Visual BASIC and use the resulting values, with all the designs available in the Experimental Design module.

Lower is Better

In case of minimizing, the occurrences of some undesirable product characteristics, one should compute the following S/N ratio:

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y^2\right] \tag{1}$$

Nominal the Best

This signal-to-noise ratio could be utilized for point perfect quality, with a specific ostensible esteem.

$$\frac{S}{N} = 10\log\frac{\bar{y}}{s_y^2} \tag{2}$$

Larger is better

Examples of these particular engineering problems are fuel economy (miles per gallon) of an automobile, strength of concrete, resistance of shielding materials, etc. The following S/N ratio should be used for the same:

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum\frac{1}{y^2}\right] \tag{3}$$

Here,

n = the number of observations on the particular product.

y = the respective characteristic

Need of Optimization Technique for Minimizing Surface Roughness

Optimization is a scientific outcome and numerical strategies, for finding and distinguishing the best competitor, from a gathering of options without having to unequivocally counting and assessing, every single conceivable option. The procedure of streamlining, lies at the base of building, since the established capacity of the designing is to outline, new, better, more effective and more affordable framework and to devise designs and techniques for the enhanced operation of the existing framework. The power of optimization strategy, to decide the best case without really testing all conceivable cases gotten using a humble level of science and at the cost of performing iterative numerical computation, utilizing plainly characterized intelligent systems or calculations embedded on processing machines. The advancement of streamlining procedure will subsequently require an office with essential vector framework controls, a touch of straight variable based math and computations and component of genuine examination. We use mathematical concepts and the construction does not simply add rigor to the proceedings.

MATERIALS AND METHODS

Design of Experiments (DOE)

A number of examinations were resolved utilizing the Taguchi technique. The Taguchi strategy is a capable and proficient design of experimental procedure, which can enhance handled execution with a base number of trials. It diminishes modifying, assembling and process duration costs, in the forms. The Taguchi configuration is to discover ideal estimations of the target work in assembling forms. Contrasted with conventional test outlines, the Taguchi technique makes utilization of an extraordinary plan of orthogonal array, to analyze the quality attributes through a base number of investigations. S/N ratio is used, to assess the execution qualities during the quality tests. In this manner, the Taguchi strategy focuses on the impacts of minor departure from quality attributes; instead of on the midpoints i.e., the Taguchi technique makes the procedure execution inhumane, to a variety of wild commotion elements. The ideal parameter conditions are then dictated by playing out the parameter outline.

Minimum Number of Experiments to Be Conducted

The design of experiments utilizing the orthogonal array is a rule for productive outcome when compared with numerous other factual outlines. The base number of tests, that are required to direct the Taguchi technique, can be figured in view of the degrees of opportunity approach.

$$N_{Taguchi} = 1 + \sum_{i=1}^{NV} L_i - 1 \quad \textbf{(4)}$$

Where,

NV = number of variables

Selection of Orthogonal Array

The impact of a wide range of parameters, on the execution trademark, in a dense arrangement of analyses can be analyzed, by utilizing the orthogonal array trial configuration, proposed by Taguchi. Once the parameters influencing a procedure could be controlled, the levels at which, these parameters ought to be differed, must be resolved. Figuring out the levels of variable, to test requires an inside out comprehension, of the procedure, including the base, most extreme and current estimation of the parameter. By chance if the distinction between the base and the most extreme estimation of a parameter is expansive, the values being tested can be separated further. If the probability of the parameter is less, then the esteems can be tested or the qualities tried could be close. Knowing the quantity of parameters and the quantity of levels, the best possible orthogonal array can be chosen.

Material (EN-8)

The "EN" nomenclature went obsolete, in 1970. But EN-8 is BS970 and 080M40 (0.08% Mn, 0.4% C), similar to SAE/AISI 1040. It is a very popular grade and is readily machinable in any conditions. It can be further surface-hardened; to produce components with enhanced wear resistance, typically in the range of fifty to fifty five HRC, through induction processes. The chemical composition of the current material utilized in this work, is shown in Table 1.

Table 1: Chemical Composition of EN-8 Steel

EN-8 Chemical Composition	
Carbon	0.36 to 0.44 %
Silicon	0.10 to 0.40 %
Manganese	0.60 to 1.00 %
Sulphur	0.050 Max
Phosphorus	0.050 Max

In this experiment, three different control factors have been taken into consideration, to find out their influence on surface roughness.

Table 2: Factor of Different Level

Factors	Level-1	Level-2	Level-3
X-Spindle Speed (RPM)	750	1500	2250
Y-Feed Rate (mm/rev)	0.1	0.2	0.3
Z- Depth of cut (mm)	0.5	1.0	1.5

Spindle Speed (S_s)

The spindle speed is the rotational recurrence of the shaft of the machine measured in insurgency, every moment (rpm).

$$S_s = \frac{V\,1000}{\pi D_i}\ rpm \quad (5)$$

Where,

S_s = spindle speed in rpm.

Di = initial diameter of the work piece in mm.

V = cutting speed in turning.

Feed Rate (F)

Feed rate is the velocity at which the cutter is feed, that is, advanced against the work piece. It is expressed in units of distance per revolution for turning and boring (mm per revolution). It is expressed as following.

$$F = \frac{F_m}{N}\ \text{mm/rev} \quad (6)$$

Where,

F_m = Feed in mm per minute.

F = Feed in mm/rev.

N = Spindle speed in rpm.

Depth of the Cut (D_c)

Depth of the cut is for all intents and purposes. It can be characterized as, the thickness of the layer being expelled (in a solitary go), from the work piece or the separation, the uncut surface of the work to the cut surface, communicated in mm.

$$D_c = \frac{D_i - d}{D_i}\ mm \tag{7}$$

Where,

D_i = initial diameter (in mm) of the job.

d = final diameter (in mm) of the job.

Flow Chart of Experiment

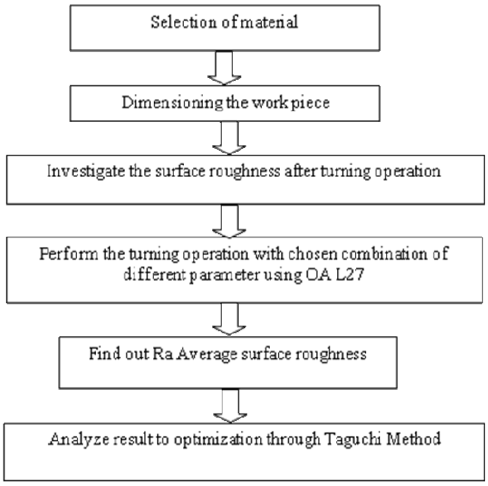

Figure 1: Process Flow Chart

Preparation of Work Piece

A rod of EN-8 material of diameter 36 mm and a length 200 mm was taken from an experiment. Machining is done on a lathe machine, using a carbide cutting tool. The experiments were conducted under dry cutting conditions. The surface roughness of finished work piece surface, were measured with the help of the surface roughness tester.

RESULTS AND DISCUSSIONS

This chapter deals with the Taguchi methods, to analyze the various parameters (spindle speed, feed rate and depth of cut) of the turning machines, for the optimization and finding, the minimum surface roughness. The analysis is carried out by the SN ratio using smaller criteria from the equation (1). These examinations were on surface roughness during hard machining of EN 8 steel.

Experimental Design

In this conduct the experiment was with three factor, at three levels each, and the fractional factorial design uses standard L-27 (3^{13}), orthogonal array. This orthogonal array is chosen, because of its ability to check the interactions among the factors. Each row of the matrix represents one experiment. However, the sequence in which these trials were carried out was randomized. The three levels of each factor were represented by 1 or 2 or 3, in the matrix. In this experiment with three factors, i.e. spindle speed (X), feed rate (Y) and depth of cut (Z) were arranged in column 1, 2 and 5 respectively, in standard L-27 (3^{13}) orthogonal array. The factors to be studied and their respective levels are shown in Table 2.

Table 3, shows the experimental result as, surface roughness and their S/N ratio of different combinations of parameters (L27 orthogonal array), in 27 experiments. For each experiment the result was measured with the help of the instrument used. These data have been taken in various combinations from the above Table 2. The S/N ratio was carried out using smaller the better characteristics.

Table 3: Experimental Results for Surface Roughness

Spindle Speed	Feed Rate	Depth Cut	R1	R2	R3	Mean Surface Roughness (Ra)	S/N Ratio
750	0.1	0.5	0.6	0.6	0.61	0.603	4.388
750	0.1	1	0	0.02	0.03	0.016	35.563
750	0.1	1.5	0.5	0.54	0.56	0.533	5.460
750	0.2	0.5	0.6	0.62	0.64	0.620	4.152
750	0.2	1	0	0.03	0.05	0.026	31.480
750	0.2	1.5	0.5	0.55	0.57	0.540	5.352
750	0.3	0.5	0.6	0.64	0.66	0.633	3.967
750	0.3	1	0	0.04	0.06	0.033	29.542
750	0.3	1.5	0.5	0.56	0.57	0.543	5.298
1500	0.1	0.5	0.6	0.6	0.62	0.606	4.340
1500	0.1	1	0	0	0.01	0.003	49.542
1500	0.1	1.5	0.6	0.63	0.63	0.620	4.152
1500	0.2	0.5	0.6	0.62	0.63	0.616	4.198
1500	0.2	1	0	0.04	0.04	0.026	31.480
1500	0.2	1.5	0.5	0.54	0.56	0.533	5.460
1500	0.3	0.5	0.6	0.63	0.65	0.626	4.0592
1500	0.3	1	0	0.04	0.07	0.036	28.714
1500	0.3	1.5	0.5	0.57	0.59	0.553	5.140
2250	0.1	0.5	0.6	0.6	0.6	0.600	4.436
2250	0.1	1	0	0.01	0.02	0.010	40.000
2250	0.1	1.5	0.5	0.53	0.54	0.5233	5.624
2250	0.2	0.5	0.6	0.6	0.62	0.606	4.340
2250	0.2	1	0	0.02	0.03	0.016	35.563
2250	0.2	1.5	0.5	0.53	0.56	0.530	5.514
2250	0.3	0.5	0.6	0.63	0.66	0.630	4.013
2250	0.3	1	0	0.03	0.05	0.026	31.480
2250	0.3	1.5	0.5	0.55	0.57	0.540	5.352

Analyzing and Evaluating Results of Experiment

The factor (spindle speed, feed rate and depth of cut) varied at three levels, for turning operation. The measured response was the impact of surface roughness. Analysis of the results was carried out analytically, as well as graphically. All the statistical calculations and plots were generated by, MINITAB 17 software.

Table 4: Response Table for Signal to Noise Ratio (Smaller is Better)

Level	Spindle Speed	Feed Rate	Depth Cut
1	13.912	17.057	4.211
2	15.232	14.171	34.819
3	15.147	13.063	5.262
Delta	1.32	3.993	30.608
Rank	3	2	1

The experimental results are shown in Table 4, as a response table. It shows the difference between the maximum value and minimum value, of the three level's mean S/N ratios. The depth of cut and feed rate are the two factors, that have the highest difference, 30.608 and 3.993, based on the response table, rank 1 and 2 respectively, as depth of cut and feed rate as shown graphically in, Figure1.

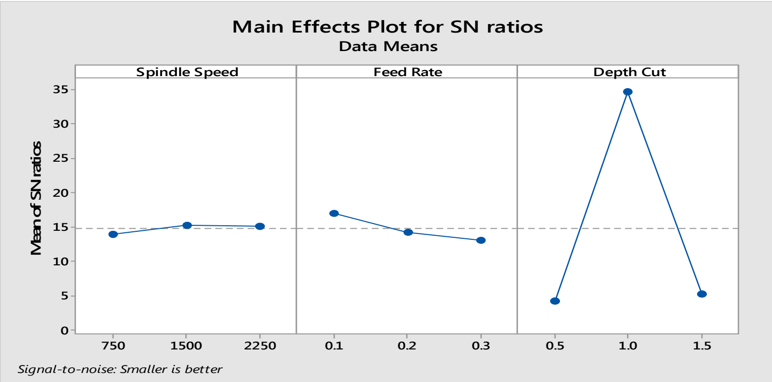

Figure 2: Main Effect Plots for S/N Ratio

Analysis of Variance (ANOVA)

In statistics, Analysis of Variance (ANOVA) is an accumulation of factual models and their related systems, in which the watched fluctuation, in a specific variable is divided into segments, inferable from various wellsprings of variety. The exploratory outcomes were investigated, utilizing examination of difference (ANOVA), for distinguishing the critical element influencing the execution measures. The results of ANOVA, for the surface roughness are shown, in Table 5.

Table 5: ANOVA for Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Spindle Speed	2	9.83	4.92	0.63	0.559
Feed Rate	2	76.5	38.25	4.88	0.041
Depth Cut	2	5434.64	2717.32	346.42	0
Spindle Speed*Feed Rate	4	23.07	5.77	0.74	0.593
Spindle Speed*Depth Cut	4	22.91	5.73	0.73	0.596
Feed Rate*Depth Cut	4	149.99	37.5	4.78	0.029
Error	8	62.75	7.84		
Total	**26**	**5779.69**			

In Table 5, ANOVA result shows that, the F value of the factor and depth of cut (factor Z), are larger than the other two cutting parameters. So the largest contribution, to the work piece surface finish, is due to the depth of cut. Depth of cut contributes 94.02 %, for surface roughness i.e., Depth of cut is a more significant factor for surface roughness.

DISCUSSIONS

In this review, utilization of Taguchi methods, for investigation of parameter and minimizing surface roughness has been applied. The depth of cut is observed to be the extensive effect, to produce low value of average surface roughness. The most important criteria in the Taguchi method, for analyzing examination data is, S/N ratio. S/N ratio should have maximum value, to obtain optimum cutting conditions, according to the Taguchi method. Thus, the optimum cutting condition was found as 49.542 S/N ratios, for surface roughness in L27 orthogonal array, in Table 3. The optimum cutting conditions, which were the cutting speed of 1500 Rpm, the feed rate of 0.1 mm/rev and depth of cut as 1 mm (1, 2,1 Orthogonal array), was acquired for the best surface roughness values. The level value of the factors obtained, for the surface roughness, according to the Taguchi design is given in, Table 4. Figure 1, shows the graph of the level values given in, Table 4, therefore; interpretation may be made according to the level values of X, Y and Z factors, as given in Table 4. Figure 1, reflects the deciding optimum cutting conditions, of investigations to be conducted under the similar conditions. The average S/N ratio, for every level of investigation is calculated on the recorded value as shown, in Table 4.

The different values of the S/N ratio, between maximum and minimum are also shown in, Table 4. The depth of cut and feed rate are two factors that have the highest difference between values, 30.608 and 3.993, respectively. In view of the Taguchi prediction, the larger difference between values of S/N ratio will have a more huge impact on surface roughness. Thus, it can be concluded that the depth of cut and feed rate, are more significant to another parameter.

Subsequently, the optimum cutting condition is determined, under the similar conditions for the analyses to be conducted, will be 1500 Rpm for the spindle speed, 0.1 mm/rev for the feed and 1.0 mm for the depth of cut.

CONCLUSIONS

From the analysis of the results in turning process, using Taguchi approach, the following can be concluded from the study:

- Depth of cut is a dominating parameter for achieving lower surface roughness, during turning of EN-8 steel.
- The ideal (optimize) parameter achieving lower surface roughness of EN-8 materials, is 1500 Rpm of cutting speed, 0.1 mm/rev of Feed and 1.0 mm Depth of cut.
- However EN-8 steel job, having superior machinability characteristics, generates sensible surface finish.
- Taguchi methods reduced the number of trials, for these parameters.
- Generally, the use of high cutting speed, low feed rate and low depth of cut, leads to better surface finish.

In the present study, only three parameters have been studied in accordance with their effects. View of future scope, other factors cutting force, wet turning and nose radius etc., can be studied. Also other outputs like power consumption and tool life can be added.

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