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Optimization of Machining Parameters for Turning Mild Steel Using Design of Experiment

Parshvam Jain *, Ranganath M S, Vipin, R. S. Mishra, Sushil Kumar, Karan Singh Tanwar
Department of Mechanical Engineering, Delhi Technological University, New Delhi,, India

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Abstract

In this paper, optimized value of cutting parameters(i.e. feed rate, cutting speed and depth of cut) and also the dominating parameter which affects the roughness of a surface produced during the turning process for mild steel are examined. Surface roughness is the quality characteristic; better surface finish affects the efficiency, performance, maintenance cost for any kinematic mechanism. So,surface roughness is very important quality characteristic. Mathematical tools taguchi method and ANNOVA (Analysis of variance) are employed to investigate the optimized value of cutting parameters for high grade of surface finish. Feed rate and cutting speed are identified as the most influential cutting parameters on surface roughness.

1. Introduction

Surface roughness is mainly a result of process parameters such as tool geometry (i.e. nose radius, edge geometry, rake angle, etc.) and cutting conditions (feed rate, cutting speed, depth of cut, etc.).Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controlled and some cannot. Controllable process parameters include feed, cutting speed, tool geometry, and tool setup. Other factors, such as tool, work piece and machine vibration, tool wear and degradation, and work piece and tool material variability cannot be controlled as easily. The important cutting parameters discussed here are cutting speed, feed and depth of cut. It is found in most of the cases surface roughness decreases with increase in cutting speed and decrease in feed and depth of cut. Since these cutting parameters will decide about the type of chips which are expected at the time of machining of a single constant material thus these have to be analyzed for no such built-up edge chips formation. The Taguchi method is statistical tool, adopted experimentally to investigate influence of surface roughness by cutting parameters such as speed, feed and depth of cut. Many researchers developed many mathematical models to optimize the cutting parameters to get lowest surface roughness by turning process. The variation in the material hardness, alloying elements present in the work piece material and other factors affecting surface finish. Proper selection of cutting parameters and tool can produce longer tool life and lower surface roughness. Hence, design of experiments by Taguchi method on cutting parameters was adopted to study the surface roughness.

2. Taguchi Method

Taguchi's parametric design is the effective tool for robust design it offers a simple and systematic qualitative optimal design to a relatively low cost. The Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments (DOE). In this project Taguchi's (DOE) approach is used to analyze the effect of process parameters like cutting speed, feed, and depth of cut on Surface Roughness of Mild steel work material while machining with cemented carbide tipped type tool and to obtain an optimal setting of these parameters that may result in good surface finish. Steps of Taguchi method are as follows:

1. Identification of main function, side effects and failure mode.
2. Identification of noise factor, testing condition and quality characteristics.
3. Identification of the main function to be optimized.
4. Identification the control factor and their levels.
5. Selection of orthogonal array and matrix experiment.
6. Conducting the matrix experiment.
7. Analyzing the data, prediction of the optimum level and performance.
8. Performing the verification experiment and planning the future action.

3. ANOVA (Analysis Of Variance)

Since there are a large number of variables controlling the process, some mathematical models are required to represent the process. However, these models are to be developed using only the significant parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the analysis of variance ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response. ANOVA can be useful for determining influence of any given input parameter from a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups. ANOVA is used in the analysis of comparative experiments, those in which only the difference

Corresponding Author,
E-mail address: parshvamjain@gmail.com

in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

4. Literature Review

Ilhan Asiltürk.et.al., [2011] have presented a paper on title "Determining the Effect of Cutting Parameters on Surface Roughness in Hard Turning Using the Taguchi Method". The study focuses on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Each experiment is repeated three times and each test uses a new cutting insert to ensure accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. S/N ratios and level values were calculated by using Eq. ''the smaller-the better'' in the MINITAB 14 Program. The results obtained in this study are as below:

- L9 orthogonal array was selected for three different levels of cutting speed, feed rate and depth of cut, which were cutting factors, by using the Taguchi method. As a result, nine experiments were conducted instead of the full factorial 27 experiments. Ra and Rz' S/N ratios were found as a result of experiments conducted according to the L9 orthogonal array. The maximum value was found by using the S/N ratio equation of ''the smaller-the better,'' the maximum S/N ratio yielded optimum cutting parameters. Optimum cutting conditions-which correspond to maximum 2.32 S/N value of the smaller Ra value for the smaller surface roughness in hard turning operation (2 1 2) were found to be 120 m/min for the cutting speed, 0.18 mm/rev for the feed rate and 0.4 mm for the depth of cut. Optimum cutting conditions-which correspond to maximum 18.75 S/N value of Rz value (3 1 1) were found to be120 m/min for the cutting speed, 0.18 mm/rev for the feed rate and 0.4 mm for the depth of cut.
- Variance analysis was applied to S/N ratios to discover interactions between cutting parameters relating to Ra and Rz. According to the ANOVA analysis, the feed rate has an effect on Ra and Rz at a reliability level of 95%. Any difference (variance) was not observed for the cutting speed and the depth of cut at the reliability level of 95%.
- The numbers of experiments in the same or similar area in hard turning operations were reduced by using the Taguchi experimental design to determine optimum cutting conditions. Satisfying results were obtained so that they may be used in future academic and industrial studies.
- Their study suggest that developed model can be used in the metal machining industries in order to determine the optimum cutting parameters for minimum surface roughness.

M Kaladhara. et. al. [2012], have presented a paper on title" Determination Of Optimum Process Parameters During Turning Of AISI 304 Austenitic Stainless Steels Using Taguchi Method ANOVA" [Ref 9].They have tried to Investigate the process parameters on surface finish and Material Removal Rate to obtain the optimal setting of these parameters. They have used ANOVA to analyze the influence of cutting parameters during machining. In their work AISI 304 Austenitic Stainless Steels work pieces were turned on CNC lathe by using physical vapor deposition coated ceramic insert (TiCN-TIN) of 0.4, and 0.8 Nose Radii. The analysis has been made with the help of a software package MINITAB 14.Their result revealed that the feed and Nose radius is the most significant process parameter on work piece surface roughness and the depth of cut and feed are the significant factor on MRR. They have also predicted optimal range and optimal level of parameters for responses with TAGUCHI Approach.

Ananthakumar. P et.al.,[2013] have presented a paper on title "Optimization Of Turning Process Parameters Using Multivariate Statistical Method-PCA Coupled With Taguchi Method[Ref 3]The work applies to optimize the process parameter for turning medium carbon steel bar using HSS tool bit via conventional machining. Optimizing one quality attribute may lead to loss of other quality attribute. Hence in order to simultaneously satisfy all the three quality requirements a multi objective optimization is required. To achieve this exploration of grey relational theory, utility concepts are attempted. To meet the basic assumption of taguchi method that quality attributes should be uncorrelated the study applies PCA based multivariate statistical method and eliminates correlation that exists in between the responses. Experiments have been conducted based on taguchi's L9 Orthogonal array design with different combinations of process control parameters: (Cutting speed, Feed, Depth of cut). Surface roughness, Material removal rate, Tool Flank wear are the response parameters that will be optimized. The obtained result will be verified through confirmatory test. This work highlights the effectiveness of proposed method for solving multi objective optimization of turning process. The above said methodology has been found fruitful in the cases where simultaneous optimization of huge responses is required. Back rack angle 10°,Side rack angle 12°,Side relief angle 07°,End relief angle 07°,Major cutting edge 15°,Minor cutting edge 15°,Nose radius 0.8 mm, Size of square tool bit 12 *12 mm2,Length of tool bit 100 mm. In this experiment HSS TOOL BITS with 10% Cobalt (SAE T42) is used. This quality of tool bits retains its hardness even at very high temperatures and is recommended where the generation of heat is very high and the tool should not get blunt at high temperatures. Work piece of standard dimensions was used for machining. Diameter of work piece: 38 mm, length of work piece: 100 mm. length of turning: 40 mm. AISI: 1040 (ISO 683-1:C40) medium carbon steel is selected for work piece material because it is used wide variety of general purpose engineering.

These steels are of particular importance because of unique combination of strength and toughness after heat treat treatment. Medium Carbon Steels are similar to low carbon steel except that the carbon ranges from 0.30 to 0.60 & the manganese from 0.50 to 0.90%. The instrument used to measure surface roughness was "Time surface roughness tester TR 100". Surface roughness readings were recorded at three locations on the work piece and the average value was used for analysis Specifications of Instrument used: Tracing length 6 mm, tracing speed 1 mm/sec, cutoff lengths 0.25 mm/0.8 mm/ 2.5 mm. Measuring range Ra:0.05- 10μm, Rz:0.1-50μm. Metzer tool maker's microscope is used to measure the cutting tool flank wear. All statistical works and including principal component analysis with proposed algorithm are performed with the help of MINITAB R14 statistical software. At the end, results of proposed algorithm are compared with the results of confirmatory test and existing methods. Here larger the better criterion is used for optimizing the overall MP Index.

From the analyses, the following conclusions have been given

1. Here the application of PCA with grey or utility based taguchi method has been recommended for the optimization of manufacturing processes like turning processes which are having correlated multiple responses to find the optimum combination of process parameters with experimental objectives.
2. PCA has been utilized here to eliminate the correlation between the responses by converting correlated responses in to uncorrelated quality indices called principal components to meet the basic assumption of taguchi optimization.
3. By comparing the existing taguchi based multi response optimization method the proposed approach meet the objectives of multiple responses simultaneously and produce best optimum combination of process parameter.
4. Over all multi response performance index based on PCA serves as a single response for solving multi response problem, really it will helpful where large number of responses to be optimized simultaneously.
5. From the experimentation and analysis depth of cut and feed showing greater influence than speed on surface roughness tool flank wear & material removal rate simultaneously.
6. The proposed approach can be recommended for off line quality control of process and product to improving the quality.

5. Experiment Set Up

5.1 Centre Lathe

Experiment was conducted on a centre lathe with work piece mounted between 3-jaw chuck and tailstock.

5.2 Cutting Tool Material

The tool used was cemented carbide insert Tip-type. The geometry of tool is: Rake angle 60 (+ve), 50 (+ve) clearance angle, 600 (+ve) major cutting edge angle, 600 (+ve) included angle and 00 cutting edge inclination angle. All the three elements-tungsten, molybdenum and cobalt help in achieving high hot hardness; the first two do so by forming complex carbides and the cobalt forms an alloy by going into solid solution in the ferrite matrix and thus raising the recrystallization temperature. Vanadium in high speed steels increases the wear resistance of tool at all operating temperatures. Vanadium also helps to inhibit grain growth at the high temperatures required in heat treatment.

5.3 Work Piece Material

Standardized material were selected to ensure consistency of the alloy, which was a common mils steel alloy used in industry in the form of bars with the size of diameter 40 mm, 100mm length so as to fit under the chuck.

The mild steel chosen for turning is actually a Heat Treatable Alloy manufactured in the form of bars. The inputs which were fed manually include dimensions of the work piece, cutting parameters depth of cut in mm, Speed available was 50-3500 rpm and feed in mm/min.This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables.

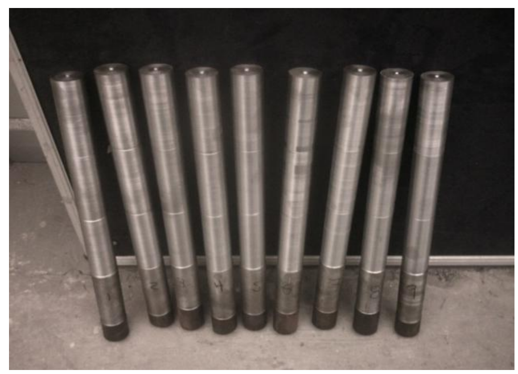

Fig: 1: Work Pieces Machined During the Experiment

Table: 1. Chemical Composition of Mild Steel Alloy

Chemical composition (Mild Steel)	
Carbon	0.16-0.18%
Silicon	0.40% max
Manganese	0.70-0.90%
Sulphur	0.040% Max
Phosphorus	0.040% Max

The different alloying elements present in a work piece are shown in the Table 1.The control factors and their levels are illustrated in Table 2. The cutting parameters ranges were selected based on machining guidelines provided by manufacturer of cutting tools.

The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument, the Surtronic 3+, is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and

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Table: 2: Cutting parameters and levels

Code	Cutting Parameter	Level 1	Level 2	Level 3
A	Depth of cut 'd' (mm)	0.6	1.2	1.8
B	Speed 's' (rpm)	156	289	409
C	Feed 'f ' (mm/rev)	0.05	0.1	0.15

Sm. The parameters evaluations and other functions of the instrument are microprocessor based. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

The dependent variable is surface roughness. Table 3 shows orthogonal array designed by Taguchi with experimental results. The left side of the Table 3 includes coding values of control factors and real values of cutting parameters. The right side of the Table 3 includes the resultsof the measured values of the surface roughness and calculated values. The left side of the Table 3 includes coding values of control factors and real values of cutting parameters. The right side of the Table 3 includes the results of the measured values of the surface roughness. The different units used here are: speed – rpm, feed mm/ rev, depth of cut – mm and surface roughness Ra - μm. Design–MINTAB software was used for Taguchi's method and for analysis of variance (ANOVA).

Fig: 2. Surtronic 3+, Roughness Testing Machine in Use

Experiment. No.	A	B	C	Depth of cut (d)	Speeds (s)	Feed (f)	Surface Roughness (Ra)
1.	1	1	1	0.6	156	0.05	3.3
2.	1	2	2	0.6	289	0.1	4.4
3.	1	3	3	0.6	409	0.15	3.1
4.	2	1	2	1.2	156	0.1	3.6
5.	2	2	3	1.2	289	0.15	4
6.	2	3	1	1.2	409	0.05	1.8
7.	3	1	3	1.8	156	0.15	3.7
8.	3	2	1	1.8	289	0.05	3.4
9.	3	3	2	1.8	409	0.1	2.9

Table: 3. Machine readings and calculations of Roughness

5.4 Surface Roughness

Surface properties such as roughness are critical to the function ability of machine components. Increased understanding of the surface generation mechanisms can be used to optimize machining process and to improve component function ability.

The present study has shown two purposes. The first was to demonstrate the use of Taguchi parameter design in order to identify the optimum surface roughness with particular combination of cutting parameters and a systematic procedure using Taguchi design in process design of turning operations. The second was to determine the optimum combination of process parameters more accurately by investigating the relative importance of process parameters using ANOVA.

5.5 Main Effect Plots Analysis

The analysis is made with the help of software package MINITAB. The main effect of plot is shown in Fig. 1 .They show the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response.

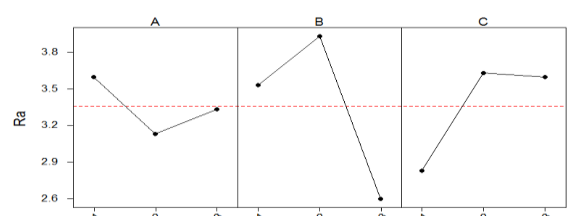

Fig: 3. Effect of Turning Parameters on Surface Roughness

The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish. According to this main effect plot, the optimal conditions for minimum surface roughness are speed at level 3 (409 RPM), feed rate at level 1 (0.05 mm/rev) and depth of cut at level 2 (1.2mm). Interaction plot for S/N ratios of the Surface roughness for data means is shown in Fig.2

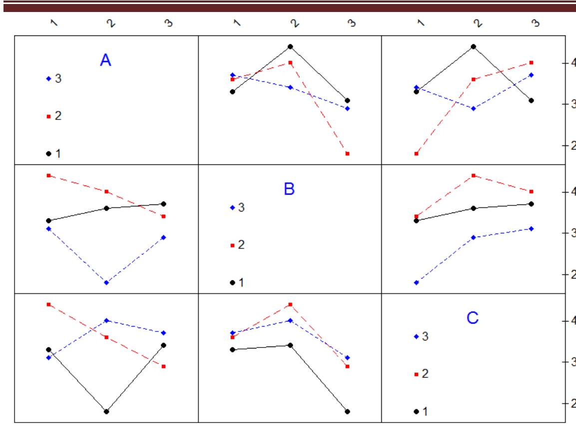

Fig: 4. Interaction Plot for of the Surface Roughness

6. Conclusions

This work presented an experimentation approach to study the impact of machining parameters on surface roughness. Strong interactions were observed among the turning parameters. Most significant interactions were found between work materials, feed and cutting speeds. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend.

The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- From the data collection it has been observed that the increase in cutting speed tends to improve the finish, thus the average surface roughness value decreases.
- The increase in depth of cut influences the finish slightly, but greater depth of cut marks the finish poor.
- Feed rate is the most critical parameter when finish is the criterion.
- Finish gets poor as the feed increases, thus the average surface roughness value increases with increase in feed.
- The ANOVA revealed that the feed is dominant parameter followed by cutting speed and depth of cut for surface roughness.
- The optimal combination process parameter for minimum surface roughness is obtained at 409rpm, 0.05 mm/rev and 1.2mm.
- Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

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