Optimization of Process Parameters for Surface Roughness During Dry Turning of Fg 260 Grey Cast Iron

Abstract: This paper investigates the effect of process parameters in dry turning of grey cast iron FG 260 on a CNC lathe. The parameters namely the spindle speed, feed rate and depth of cut are varied to study their effect on surface roughness. The study reveals that surface roughness is directly influenced by the feed rate and spindle speed. It is observed that surface roughness increases with increased feed rate and is higher at lower speeds .In this investigation, an effective approach based on Taguchi method, analysis of variance (ANOVA), multivariable linear regression (MVLR), has been developed to determine the optimum conditions leading to minimum surface roughness value. Experiments were conducted by varying spindle speed, feed rate and depth of cut using L9 orthogonal array of Taguchi method. The present work aims at optimizing process parameters to achieve minimum surface roughness Ra. Experimental results from the orthogonal array were used as the training data for the MVLR model to map the relationship between process parameters and SR the experiment was conducted on CNC lathe machine. From the investigation It concludes that feed rate is most influencing parameter followed spindle speed and depth of cut.

Keywords: Dry turning, NOVA, Taguchi, MVLR analysis, SR

1. Introduction

In metal cutting and manufacturing industries, surface finish of a product is very crucial in determining the quality. Good surface finish not only assures quality, but also reduces manufacturing cost. Surface finish is important in terms of tolerances, it reduces assembly time and avoids the need for secondary operation, thus reduces operation time and leads to overall cost reduction. Besides, good-quality turned surface is significant in improving fatigue strength, corrosion resistance, and creep life. Due to the increasing demand of higher precision components for its functional aspect, surface roughness of a machined part plays an important role in the modern manufacturing process. The quality of the surface plays a very important role in the performance of turning as a good quality turned surface significantly improves fatigue strength, corrosion resistance, or creep life. Surface roughness also affects several functional attributes of parts, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, load bearing capacity, coating or resisting fatigue. Therefore, the desired surface finish is usually specified and the appropriate processes are selected to reach the required quality [1]. The increasing demand for comfortable and healthy workplaces for machine industry employees has encouraged manufacturers to implement dry machining strategies [2]. The first step in implementing these strategies is running the machining process without cutting fluids, otherwise known as dry machining. Traditionally, the application of cutting fluids has been commonly used to increase the performance of the machining process. The advantages of cutting fluids include the removal of friction-induced heat, which is generated during cutting, increased tool life, improved surface finish, preventing the formation of built-up edges, and facilitating the transportation of chips. However, many issues surround the use of cutting fluids , including worker health and safety concerns, fluid system maintenance, fluid pretreatment disposal, and environmental concerns[2,3].. Owing to these negative impacts of cutting fluids, dry machining is becoming an increasingly popular trend in the machining industry, to ensure workers' health and a safe work environment. Its benefits include savings in the purchase of cutting fluids, reduced manufacturing costs, reduced disposal costs, less impact on the environment, and improved health conditions for operators in the workshop [3]. Dry machining is ecologically desirable and is expected to be considered as a necessity in manufacturing enterprises in the near future. Industries will be compelled to consider dry machining, in order to comply with environmental protection laws for

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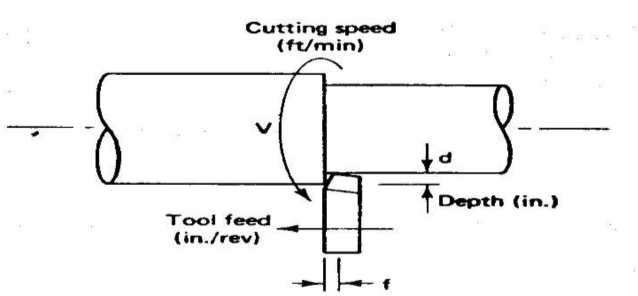
occupational safety and health regulations [4]. Dry machining applications are highly dependent on the selection of appropriate cutting tools, cutting parameters, and types of workpiece material. Advanced wear resistance, which increases oxidation resistance in the coating, offers an advantage for the dry machining of cast iron, alloyed steel, and aluminium with 10% Si,due to its low thermal conductivity[5]. There are many ways to improve the performance of dry machining, one of which is the development of the coatings that are applied to the cutting tools. Recent statistics reveal that 80% of all machining operations use coated cutting tools [6]. On average, coatings increase tool costs by only 10% [7]. Several years ago, the leading tool coating material was aluminium oxide. Today, coatings based on titanium nitride (TiN), titanium carbon nitride (TiCN), and titanium aluminium nitride (TiAlN), have been developed to withstand more severe operating conditions. Notably,TiAlN exhibits thermal stability up to 900 _C, [7,8]. reported that AlCrN coated tools are suitable for high speed cutting under dry conditions. [9]investigated the performance of coated and uncoated cutting tools turning nodular cast iron under dry conditions. They found that multilayer coated tools were the most suitable for turning nodular cast irons at high cutting speeds.

Cast iron materials can mostly be dry cut in turning and milling operations. Cast iron materials are especially favorable in this respect, because their cutting temperatures are significantly lower than those of steel.

Turning is the process whereby a single point cutting tool removes unwanted material from the cylindrical work piece and the tool is fed parallel to the axis of rotation. It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not. Turning, in which material is removed from the external surface of a rotating workpiece, is one of the most basic material removal processes. Therefore, turning is the first

Choice for machining cylindrical parts.



Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed.

Turning, like any other machining process, is greatly influenced by independent input variables cutting speed, feed rate, and depth of cut commonly known as cutting conditions.

Use of cast iron in the automotive industry has grown dramatically in recent years Gray cast iron is considered to have good machinability such as low wear rate, high metal removal rate, relatively low tool forces and low power consumption [10]. A major reason for the continued large scale use of cast iron in engineering is not only the low cost of the material and the casting process but also the economics of machining the finished component. Grey cast iron is widely used to fabricate components such as engine blocks, cylinder heads, motor casings flywheels, and cylinder liners etc.

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2. EXPERIMENTAL DETAILS

a) Design of experiments: Taguchi and Konishi had developed Taguchi techniques [11] these techniques have been utilized widely in engineering analysis to optimize the performance characteristics within the combination of design parameters. Taguchi technique is also power tool for the design of high quality systems. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance, and computational cost [12]. In this study we have consider 3 factors which affect majorly on quality characteristic such as (A) spindle speed., (B) feed rate (C) depth of cut, . The design of experiment was carried out by Taguchi methodology using Minitab 14 software. In this technique the main objective is to optimize surface roughness Ra of turning that is influenced by various process parameters

b) Selection of control factors: From the discussion with company peoples strongly felt that turning bears a direct relationship with surface roughness. So that surface roughness is selected as response parameter for experimentation.

c) Selection of orthogonal array: Since 3 controllable factors and three levels of each factor were considered L9 (3**3) Orthogonal Array was selected for this study

d) Experimental set up: A Series of experiment was conducted to evaluate the influence of parameters on surface roughness. The experiments were carried out on CNC lathe machine The CNC lathe machine (Figure 2.1) has the following specifications:

Chuck size	170mm
Max.Turning Dia.	250mm
Max.Turning Length	350mm
Travel X/Z axes	200mm/350mm
Rapid Feed rateX/Z axes	24m/min
Spindle 30mm/rating	9.25/7KW
Spindle speed Range	50-4500rpm
Tooling System	8st.Servo Turret
Input Voltage	415+or-10%Voltage
Input Power	20KW
Spindle power	05/07KW
Working Temp.	10degree C to 50 degree C
Machine Weight	3000kg.

Figure 1 Pictorial View of CNC lathe

e) Work material and Tool:

Work piece material for the present work is grey cast iron (FG260) a bar of dimension 90mm length and 40 mm diameter is used. Chemical composition of the material used is C3.3%, Si2.05%, Mn1.02%, S 0.08%, P 0.09%. Tool used in the research is CVD – TiN-TiCN-Al2O3 coated carbide carbide (K20) tool from WIDIA (TPGN 16 03 04 H13A manufacturer code). Tool geometry is defined by rake angle 6^o, clearance angle 11^o, tool cutting edge angle 91^o, cutting edge inclination angle $0^o$and tool nose radius 0.4 mm and a type PCLNL 1616 K12 (ISO) tool holder from WIDIA was used.

f) Surface roughness measurement:

Surface roughness Ra is the rate at which the material is removed from the work piece. Turning operation takes place between the tool and the work piece during the machining process material is removed

3. Experimental conditions

The experiments were carried out on CNC lathe for Surface roughness there are three input controlling factors selected having three levels. Details of parameters and their levels used shown in the table 3.1

TABLE 1. PROCESS PARAMETERS AND LEVELS

A	SPEED (m/min)	230	260	290
B	FEED (rev/min	0.10	0.25	0.40
C	DOC (mm)	0.5	1	1.5

TABLE 2. LAYOUT FOR EXPERIMENTAL DESIGN ACCORDING TO L9 ARRAY

Sr.N0	SPEED	FEED	DOC
1	230	0.10	0.5
2	230	0.25	1.0
3	230	0.40	1.5
4	260	0.10	1.0
5	260	0.25	1.5
6	260	0.40	0.5
7	290	0.10	1.5
8	290	0.25	0.5
9	290	0.40	1.0

4. Results and Discussion

a) S/N Ratio Analysis- In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (LB). Lower is better S/N ratio used here. Lower the better quality characteristic was implemented and introduced in this study.

For the smaller the better characteristic

S/N = -10 log10 (MSD)

Where MSD= Mean Squared Division

$$\mathbf{MSD = (Y_1^2 + Y_2^2 + Y_3^2 + \ldots\ldots\ldots\ldots)/n}$$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and MSD is the target value of the result. The level of a factor with the highest S/N ratio was the optimum level for responses measured. Table 4.1 and Figure 4.1 depict the factor effect on surface roughness. The lower the signal to noise ratio, the more favorable is the effect of the input variable on the output.

TABLE 3. SUMMARY REPORT FOR DIFFERENT TRIALS CONDUCTED DURING EXPERIMENTATION

Level	SPEED	FEED	DOC
1	-10.763	-4.981	-7.974
2	-8.054	-8.563	-9.194
3	-6.966	-12.240	-8.615
Delta	3.797	7.259	1.220
Rank	2	1	3

TABLE 4.ESTIMATED MODEL COEFFICIENTS FOR SN RATIOS

Term	Coef	SE Coef	T	P
Constant	-8.59445	0.2874	-29.90	0.001
SPEED 230	-2.16872	0.4064	-5.336	0.033
SPEED 260	0.53996	0.4064	1.329	0.315
FEED 0.10	3.61377	0.4064	8.892	0.012
FEED 0.25	0.03158	0.4064	0.078	0.945
DOC 0.5	0.62031	0.4064	1.526	0.266
DOC 1.0	-0.59971	0.4064	-1.476	0.278

Summary of Model-

S = 0.8621 R-Sq = 98.6% R-Sq (adj) = 94.4%

TABLE 5. RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

SPEED	FEED	DOC	Ra
230	0.10	0.5	2.1
230	0.25	1.0	3.5
230	0.40	1.5	5.6
260	0.10	1.0	1.9
260	0.25	1.5	2.5
260	0.40	0.5	3.4
290	0.10	1.5	1.4
290	0.25	0.5	2.2
290	0.40	1.0	3.6

From the Table 4.1 and Figure 4.1 it is clear that, the optimum value levels for lower surface roughness are at speed (290), feed (0.1), and depth of cut (1.5). Also, for surface roughness, from it can be seen that, the most significant factor is feed rate (B), followed by Speed (A) and Depth of cut (C).

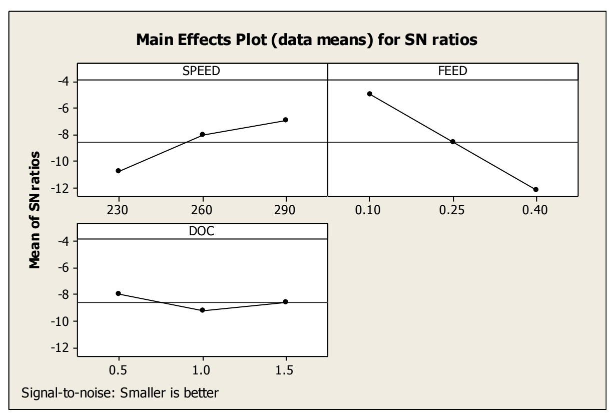

Figure 2. Effect of process parameters on S/N Ratio

b) Analysis of Variance (ANOVA): Analysis of variance is a standard statistical technique to interpret experimental results. It is extensively used to detect differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus finds the parameters whose contribution to total variation is significant. Thus analysis of variance is used to study the relative influences of multiple variables, and their significance

The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for design of experiment applications. In order to find out statistical Significance of various factors like speed (A), feed (B), and depth of cut (C), and their interactions on Ra, analysis of variance (ANOVA) is performed on experimental data. Table 4.2 shows the result of the ANOVA with the Ra. The last column of the table indicates p-value for the individual control factors. It is known that smaller the p-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 4.4) indicate that, the speed (s=290), feed (f= 0.10) and depth of cut (doc=01.5) in this order, are significant control factors effecting Ra. It means, the feed rate is the most significant factor and the depth of cut. Has less influence on the performance output.

TABLE 6. ANALYSIS OF VARIANCE FOR SN RATIOS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SPEED	2	22.943	22.943	11.47	15.44	0.061
FEED	2	79.047	79.047	39.52	53.18	0.018
DOC	2	2.235	2.235	1.11	1.5	0.399
Residual Error	2	1.486	1.486	0.74		
Total	8	105.711				

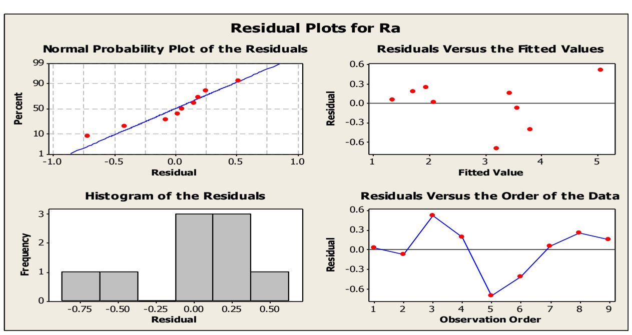

Figure 3. Residual Plots for Ra

d) Regression Analysis- Regression analysis is used for explaining or modeling the relationship between a single variable Y, called the response, output or dependent variable, and one or more predictor, input, independent or explanatory variables Mathematical models for process parameters such as speed . , feed and depth of cut were obtained from regression analysis using MINITAB 14 statistical software to predict Ra.

The regression equation is

Y = 6.09 + 0.600 DOC + 8.00 FEED - 0.0222 SPEED

S = 0.465236 R-Sq = 91.6% R-Sq(adj) = 86.6%

Where,

Y = Response i.e.Ra µm

A = Speed (m/min), B = Feed rate (mm/rev), C = depth of cut (mm),

If we put optimum parameters which are drawn by ANOVA in equation 1 it will give optimum value of quality characteristic which will minimize Ra.

Yopt = 6.09 + 0.600 DOC + 8.00 FEED - 0.0222 SPEED

Yopt = 6.09+0.600*1.5+8.0*0.1-0.0222*290

Yopt = 1.352µm

(Predicted by Regression Equation)

In multiple linear regression analysis, R2 is value of the correlation coefficient and should be between 0.8 and 1. In this study, results obtained from Ra in good agreement with regression models (R2>0.80).

Observation	Optimum Experimental value of Ra	Optimum Predicted Value	S/N Ratio
	1.4	1.352	-2.9226

5. CONCLUSIONS

The Taguchi method was applied to find an optimal setting of the surface roughness Ra parameters process. The result from the Taguchi method chooses an optimal solution from combinations of factors if it gives maximized normalized combined S/N ratio of targeted outputs. The L-9 OA was used to accommodate three control factors and each with 3 levels for experimental plan selected process parameters are Speed. (230,260, 290), Feed rate (0.10, 0.25, 0.40), Depth of cut (0.5, 1, 1.5). The results are summarized as follows:

- Among three process parameters Feed rate followed by Speed and Depth of cut was most influencing parameters on Ra
- The Optimal level of process parameter were found to be A3B1C3
- The prediction made by Taguchi parameter design technique is in good agreement with confirmation results
- The result of present investigation are valid within specified range of process parameters
- Also the prediction made by Regression Analysis is in good agreement with

- The optimal levels of Ra process parameters for optimum Ra are:

Speed. (m/min)	290
Feed rate (mm/rev)	0.1
Depth of cut (mm)	1.5

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