Effect Of Reaming Process Parameters On Surface Roughness Using Taguchi Method

Roshani U. Shingarwade
ME Scholar, Mechanical Engineering Department, Government College of Engineering, Aurangabad

Prof. M. S. Harne
Asst. Professor, Mechanical Engineering Department, Government College of Engineering, Aurangabad

Abstract

In this paper, reaming operation with two different mineral based cutting fluids were carried out to determine optimum conditions for surface roughness during reaming of grey cast iron of grade SAE D7003. K20 cemented carbide reamer was used as cutting tool. Taguchi L9 orthogonal array was used for the experiment plan. Spindle speed, feed rate, reverse feed rate were considered as machining parameters. Mathematical models for cutting parameters were obtained from regression analyses to predict values of surface roughness. S/N ratio and ANOVA analyses were also performed to identify significant parameters influencing surface roughness. The test results shows that satisfactory hole quality can be achieved during reaming by employing high spindle speed, low feed rate and low reverse feed rate.

Keywords: *Reaming, Surface Roughness, Mathematical Model, ANOVA, Taguchi Technique*

1. Introduction

Reaming is a common machining process widely used in automotive industry with the characteristic property of enlarging, smoothing and accurately sizing existing holes to tight tolerances. The quality of the hole depends on reamer geometry, cutting conditions, application, stock removal, cutting fluid, and the quality of the holes to be reamed [1]. In addition to this many independent influencing parameters are connected to the operator, his experience in performing cutting, choosing the correct measuring strategy and final data processing and evaluation. Therefore, a complete control over these influence quantities is necessary [5]. In reaming, speed and feed are important; stock removal and alignment must be considered in order to produce chatter-free holes. Reaming speeds for machine reaming may vary considerably depending in part on the material to be reamed, type of machine, and required finish and accuracy. Reaming is a finishing operation which normally follows drilling or core drilling. Since stock removal is small and must be uniform in reaming, the starting holes (drilled or otherwise produced) must have relatively good roundness, straightness, and surface finish. Reamers tend to follow the existing centreline of the hole being reamed. If insufficient stock removal is left in the hole before reaming, the reamer can wear faster than normally and result in loss of diameter accuracy. In general applications, average surface roughness for reaming is expected to be in range between 0.8μm and 3.2μm but high-accuracy reaming can produce average surface [1].

Modern machining requirements often demand mass production of holes with good surface finish and geometrical accuracy which are needed for precision assembly. In practice the holes are created with twist drills and reaming is performed as a secondary operation where a single tool can be used to ream a large number of holes [2].

Cutting fluids applied in machining provide lubrication and cooling, minimizing the heat produced between the surface of the workpiece and the tool and the contact area between tool and chip. Cutting fluids improve the efficiency of machining in terms of increased tool life, improved surface finish, improved tolerances, reduced cutting force and reduced vibrations. The effect of using a cutting fluid depends not only on the properties of the fluid, but also on the machining conditions, i.e. on tool and work materials, tool geometry and speeds [3].

Leonardo De Chiffre and S. Muller investigated the reaming using minimal quantity lubrication. It was observed that a higher federate leads to lower and more repeatable roughness, but at the same time to higher and less repeatable reaming thrust and torque when reaming of austenitic stainless steel [1]. A.A Bezerra focused on the effect of machining parameters when reaming Aluminium –Silicon (SAE 322) alloy on dimensional stability and surface roughness. Reaming at higher feed conditions improves the accuracy of holes produced at the expense of an increase in power consumption and deterioration in the surface finish generated [2]. W. Belluco and L. De. Chiffre studied the effect of new formulations of vegetable oils on surface integrity and part accuracy in reaming and tapping operations with AISI 316L stainless steel [3]. K. Ohgo, A. Satoh, T. Mizuno, T. Itoh, studied the relation between cutting conditions and precision in the reaming of grey iron casting. It was shown that a built-up edge and the presence of chips have an unfavorable influence on precision. The use of a left helix reamer with a two-stage chamfer when a very small amount of soluble cutting fluid mist is blown on to the tool yielded the same high precision as when a coolant is used [6].

In this study, two different cutting fluids based on mineral oil were used to optimize cutting parameters for surface roughness during reaming of grey cast iron of grade SAE D7003. Brainstorming session with the experts in the area of manufacturing, design and maintenance was carried out to select the parameters that may be taken into consideration. The three input parameters namely spindle speed, feed rate and reverse feed rate were selected after brainstorming for final experimentation. Pre-experimentation was carried out for selecting the ranges of process parameters before designing experimental runs. Taguchi L9 orthogonal array is employed to analyze experimental results of machining obtained from 9 experiments for finish machining individually by varying three process parameters. ANOVA has been performed and compared with Taguchi method.

2. Experimental Details

2.1 Taguchi Method

Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use.

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process from data already in existence.

Taguchi method based design of experiments has been used to study effect of three machining parameters [Spindle speed (rpm), feed rate (mm/min) and reverse feed rate (mm/min)] each at three levels were considered and are listed in Table 1 on important output parameter i.e. Surface roughness (Ra) while other parameters have been assumed to be constant.

Table 1 Machining parameters and their levels

Levels	Speed (rpm)	Feed (mm/min)	Reverse feed rate(mm/min)
1	900	90	5000
2	1200	135	7500
3	1500	180	10000

2.2 Mineral based cutting fluid

Cutting fluids based on mineral oils are normally used for their low costs and chemical stability. In metalworking operations, the frictional resistance can be reduced by adding a lubricant between the surfaces. Lubricants separate the sliding surfaces by forming a film, and thereby reduce the frictional resistance and wear [7]. Mineral based cutting oils with different characteristics are considered in this work (Table 2). The oil concentration was 5% during experimental test. The concentration of oil in water was measured by refractometer.

Table 2 Characterization of mineral based cutting oil

Metal cutting fluid	Density(g/cm^{3})	Viscosity40 °C (mm2/sec)	Flash point (°C)
Blazer 40000 (A)	0.99 at 20˚C	58	99
IPOL cut 140AS (B)	0.88 at 15˚C	25	156

2.3 Response variables selected

Ra is used to describe the roughness of machined surfaces. It is useful for detecting general variations in overall profile height characteristics and for monitoring an established manufacturing process. Hence, in present study the roughness parameter Ra have been selected as the response variable.

2.4 Equipment and tools used

All the reaming tests were carried out on SLIM MAKINO 3 PC four axes CNC vertical milling centre equipped with a maximum spindle speed of 15000 rpm and a 15 kW spindle power. The K20 solid carbide 6-flute straight reamer with Ø18.821mm was used for the test. Reamer specifications and dimensions are listed in Table 3. Reamer was clamped in hydrogrip.

Table 3 Reamer specification

Material	K 20 solid carbide
No. of flutes	**6**
Shank	Cylindrical
Helix angle	0˚
Chamfer	1×45˚
Dimensions(mm)	
Overall length *l1*	134
Flute length *l2*	32
Cutting diameter d1	18.82
Shank diameter d2	20
Back taper	0.016

2.5 Workpiece material

The present study was carried out with casting from grey cast iron of grade SAE D7003 as a workpiece material. Cylindrical specimens of reverse shift fork of dimensions 50mm long hole without chamfer were produced with pre-manufactured holes Ø18.5mm by drilling. Workpiece were clamped in holder so that the workpiece were fully immersed in cutting fluid. The chemical composition (percent by weight), and the mechanical properties of the workpiece material is given in Table 4.

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Table 1 Chemical composition of Grey cast iron

Element	%
C	3.3
Mn	0.33
Cr	0.02
Cu	1.07
Mg	0.0308
S	0.011
P	0.0125
Si	2.3

Brinell Hardness Number (BHN)	255
% Elongation	5.05
Tensile Strength, Ultimate	83
Yield Strength	58

2.6 Roughness measurement

Surface roughness Ra was measured with skid stylus roughness tester Mitutoyo (Model SJ 401). Evaluation range is 20mm and stylus with diamond tip of 5μm. Measurements was taken at inner side of bore surface at both ends. Total 6 readings were recorded at different positions per sample.

2.7 Experimental conditions

Key machining parameters (Spindle speed, feed rate and reverse feed rate) were varied according to the experiment plan while the remaining parameters were kept at the following values: Depth of cut = 0.167mm, oil flow rate = 20 l/min. Oil pressure = 6bar, clamping pressure= 70bar.

3. Results and Discussions

The experiments were conducted based on Taguchi Model and runs were randomized, the results were obtained. The analysis of the experimental data was carried out using MINITAB 14 software, which is specially used for DOE applications. The Experimental results were transformed to signal to noise (S/N). The S/N ratio for surface roughness using “Smaller the better” characteristic are calculated. The experimental results for surface roughness were given in Table 5.

Table 5 Experimental Results

Speed	Feed	Reverse feed rate	Ra (A)	Ra(B)
900	90	5000	0.99	1.20
900	135	7500	1.37	1.44
900	180	10000	1.9	1.95
1200	90	7500	0.8	0.99
1200	135	10000	1.23	1.37
1200	180	5000	1.52	1.43
1500	90	10000	0.65	0.91
1500	135	5000	0.94	1.06
1500	180	7500	1.32	1.38

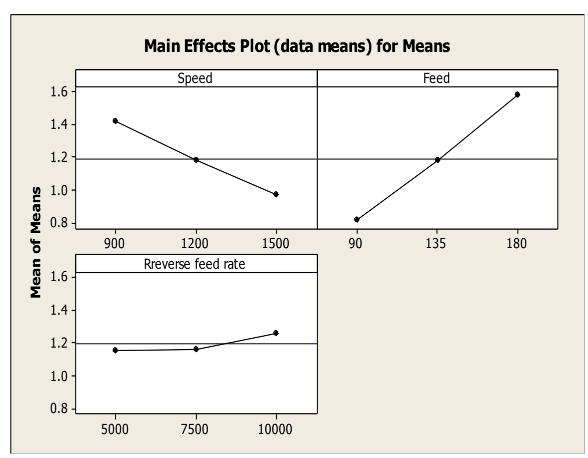

Figure1. Main effects plot for Ra(A)

It is clear from main effect plot as shown in figure 1 and 2 that feed is the most significant factor affecting on surface roughness. The graph shows that surface roughness for cutting fluid A and B increases with the increase in feed rate from 90 mm/min to 180 mm/min. The Speed is the second most significant factor, surface roughness decreases with decrease in speed. For reverse feed rate, the minimum surface roughness was obtained at 5000 mm/min.

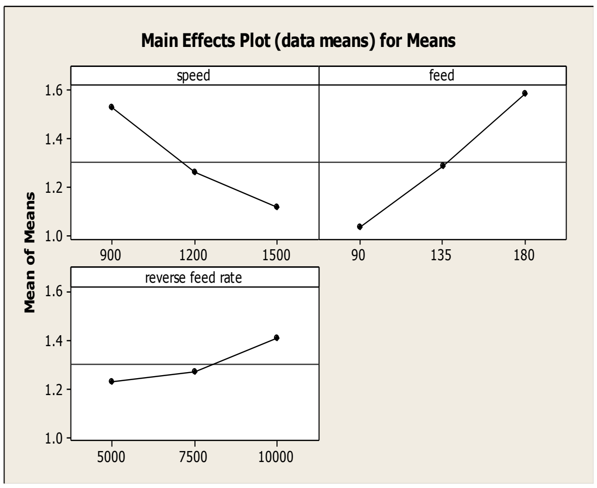

Figure 2 Main effect plot for Ra (B)

3.1 ANOVA (Analysis of Variance)

Taguchi method cannot judge and determine effect of individual parameter on entire process while percentage contribution of individual parameters can be well determined using ANOVA [8]. So ANOVA helps us to compare variability within experimental data. MINTAB 14 software was employed to investigate effect of process parameters. It is clear from the ANOVA for surface roughness that all the chosen process parameters have significant influence on Ra (A) & Ra (B) (P value <= 0.05; 95% confidence level). P-value of parameters indicates that feed is significantly contributing towards surface roughness (Table 6&7). It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95 % confidence level.

Best parameters for surface roughness for cutting fluids of both A and B are (Table 8& 9) [speed 1500rpm (level 3); feed 90mm/min (level 1) and reverse feed rate 5000mm/min (level1)].

Table 6 Analysis of Variance for Ra (A)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.30402	0.304022	0.152011	136.81	0.007
Feed	2	0.88222	0.882222	0.441111	397.00	0.003
Reverse feed rate	2	0.02162	0.021622	0.010811	49.73	0.093
Residual Error	2	0.00222	0.002222	0.001111		
Total	8	1.21009				

Table 7 Analysis of Variance for Ra(B)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.263467	0.263467	0.131733	29.71	0.033
Feed	2	0.460067	0.460067	0.230033	51.89	0.019
Reverse feed rate	2	0.053600	0.053600	0.026800	6.05	0.142
Residual Error	2	0.008867	0.008867	0.004433		
Total	8	0.786000				

Table 8 Response Table for Means of Ra (A)

Level	Speed	Feed	Reverse feed rate
1	1.4200	**0.8133**	**1.1500**
2	1.1833	1.1800	1.1633
3	**0.9700**	1.5800	1.2600
Delta	0.4500	0.7667	0.1100
Rank	2	1	3

Table 9 Response Table for Means of Ra (B)

Level	Speed	Feed	Reverse feed rate
1	1.530	**1.033**	**1.230**
2	1.263	1.290	1.270
3	**1.117**	1.587	1.410
Delta	0.413	0.553	0.180
Rank	2	1	3

3.2 Analysis of S/N

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 higher is better (HB). Smaller is better S/N ratio was used in this study because a lower surface roughness were desirable. Quality characteristic of the smaller is better is calculated in the following equation

$$\eta = -10\log\left[\frac{1}{n}\left(\sum_{i=1}^{n} y_i^2\right)\right]$$

where *n* is number of measurements in a trial/row and *yi* is the *i*th measured value in a run/row[7]. The S/N ratio values calculated by taking above equation into consideration were listed in Table 10 for surface roughness of cutting fluid A & B. Figures 3&4 showed the main effects plot for S/N ratios. The level of a factor with the highest S/N ratio was the optimum level for responses measured.

Table 10 Values of S/N ratios for Ra (A) and Ra (B)

Speed	Feed	Reverse feed rate	Ra (A)	SNRA1	Ra(B)	SNRA1
900	90	5000	0.99	0.0873	1.2	-1.58362
900	135	7500	1.37	-2.73441	1.44	-3.16725
900	180	10000	1.9	-5.57507	1.95	-5.80069
1200	90	7500	0.8	1.9382	0.99	0.0873
1200	135	10000	1.23	-1.7981	1.37	-2.73441
1200	180	5000	1.52	-3.63687	1.43	-3.10672
1500	90	10000	0.65	3.74173	0.91	0.81917
1500	135	5000	0.94	0.53744	1.06	-0.50612
1500	180	7500	1.32	-2.41148	1.38	-2.79758

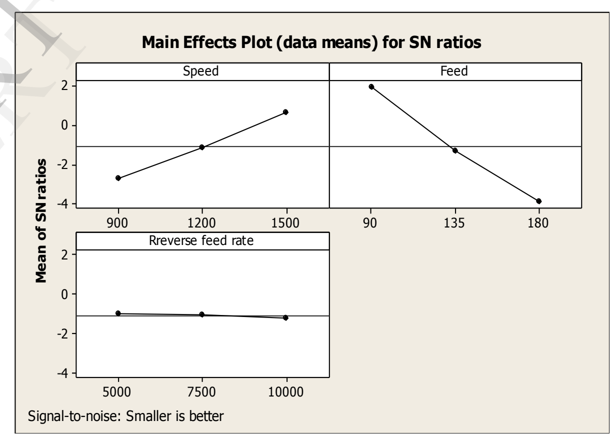

Figure 3 S/N ratio values for Ra(A)

From the S/N ratio analysis in Fig. 3&4, the optimal machining conditions were 1500 rpm spindle speed (level 3), 90 mm/min feed rate (level 1), 5000 mm/min reverse feed rate (level 1) for surface roughness of cutting fluid A and B.

Best process parameters corresponding to surface roughness are spindle speed 1500 rpm, feed 90mm/min and reverse feed rate 5000 mm/min. Significance of machining parameters (difference between maximum and minimum value i.e. delta) indicates that feed is significantly contributing towards machining performance as difference gives higher values (Table13&14). Therefore, most influencing parameter is feed. Study finds that optimized process parameters are speed 1500rpm. Feed 90mm/min and reverse feed rate 5000mm/min.

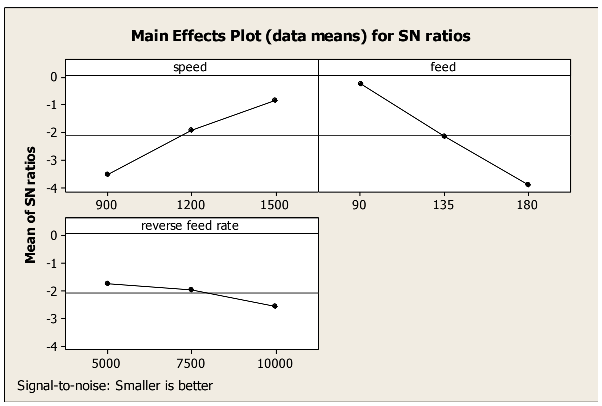

Figure 4 S/N ratio values for Ra (B)

Table 11 Response Table for Signal to Noise Ratios Smaller is better for Ra (A)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	16.9903	16.9903	8.4952	43.75	0.022
Feed	2	50.6588	50.6588	25.3294	130.44	0.008
Reverse Feed Rate	2	0.0668	0.0668	0.0334	0.17	0.853
Residual Error	2	0.3884	0.3884	0.1942		
Total	8	68.1043				

Table 12 Response Table for Signal to Noise Ratios Smaller is better for Ra(B)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	10.9760	10.9760	5.4880	23.83	0.040
Feed	2	20.2793	20.2793	10.1397	44.02	0.022
Reverse Feed Rate	2	1.1324	1.1324	0.5662	2.46	0.289
Residual Error	2	0.4607	0.4607	0.2303		
Total	8	32.8483				

Table 13 Response Table for S/N ratios for Ra(A)

Level	Speed	Feed	Reverse feed rate
1	-2.7407	**1.9224**	**-1.0040**
2	-1.1656	-1.3317	-1.0692
3	**0.6226**	-3.8745	-1.2105
Delta	3.3633	5.7969	0.2064
Rank	2	1	3

Table 14 Response Table for S/N ratios for Ra (B)

Level	Speed	Feed	Reverse feed rate
1	-3.5172	**-0.2257**	**-1.7322**
2	-1.9179	-2/1359	-1.9592
3	**-0.8282**	-3.9017	-2.5720
Delta	2.6890	3.6759	0.8398
Rank	2	1	3

3.3 Regression Analysis

Mathematical models for cutting parameters such as spindle speed, feed, reverse feed rate were obtained from regression analysis using MINITAB 14 statistical software to predict surface roughness for each cutting fluid. The regression equation for Ra (A) and Ra (B) are as follows:
The regression equations are:

Ra (A) = 0.776 - 0.000750 Speed + 0.00852 Feed + 0.000022 Reverse feed rate

S = 0.0361171 R-Sq = 99.5% R-Sq(adj) = 99.1%

Ra (B) = 1.03 - 0.000689 Speed + 0.00615 Feed + 0.000036 Reverse feed rate

S = 0.0661312 R-Sq = 97.2% R-Sq(adj) = 95.5%

In multiple linear regression analysis, R-sq is value of the correlation coefficient and should be between 0.8 and1. In this study, results obtained from surface roughness 0f fluid A & B were in good agreement with regression models (R2>0.80).

3.4 Confirmation Test

Confirmation test were carried out because the optimum combination of parameters and their levels in the present study did not match with any experiment of the orthogonal array. The surface roughness of cutting fluid A&B at optimal combination of parameters and their levels was conducted and its values were measured. The estimated value of surface roughness at optimum condition was also computed. Table 15&16 shows a comparison between the estimated value of Ra at optimum condition and the experimental value. A small difference can be observed between these values. This indicates that the experimental value is close to the estimated value. Therefore, this verifies that the experimental result is highly correlated with the estimated result.

Table 15 Results of confirmation experiment for Ra(A)

Experimental run	Confirmation test results	Calculated values	% Error
1	0.50	0.5278	5.56
2	0.49	0.5278	7.71
3	0.51	0.5278	3.49

Table 16 Results of confirmation experiment for Ra (B)

Experimental run	Confirmation test results	Calculated values	% Error
1	0.67	0.73	8.95
2	0.69	0.73	5.79
3	0.68	0.73	7.35

4. Conclusions

An investigation was carried out to compare cutting fluid efficiency with respect to optimum surface roughness in reaming. Two types of mineral based cutting oil were investigated while cutting grey cast iron of grade SAE D7003. K20 cemented carbide reamer was used as cutting tool. In these experiments, different cutting speed, feed rate and reverse feed rate were utilized for two types of cutting fluid. Multiple regression analysis was performed to indicate the fitness of experimental measurements. Regression models obtained from Ra (A) and Ra (B) measurements matched very well with the experimental data (R-Sq >0.80). The level of importance of the machining parameters on the surface roughness was determined by ANOVA. Based on this study, the following conclusions can be drawn for the reaming conditions:

1. The mineral based cutting oil A resulted in comparable or better performance than oil B.
2. The optimal machining condition for surface roughness of A&B was 1500 rpm spindle speed (level 3), 90 mm/min feed (level 1), 5000mm/min reverse feed rate (level 1).
3. Feed and spindle speed are the most influencing parameter corresponding to quality characteristics of surface roughness.

Reverse feed rate is least significant as compared to speed and feed.

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