IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 04, Issue 10 (October. 2014), ||V1|| PP 01-10

Optimization of cutting parameters for surface roughness in CNC turning machining with aluminum alloy 6061 material

Ali Abdallah[1], Bhuvenesh Rajamony[2] Abdulnasser Embark[3]
[1](School of Manufacturing Engineering, Universiti Malaysia Perlis, Kampus Tetap Ulu Pauh, Jalan Arau – Changlun, 02600 Arau, Perlis, Malaysia)
[23](School of Manufacturing Engineering, Universiti Malaysia Perlis, Kampus Tetap Ulu Pauh, Jalan Arau – Changlun, 02600 Arau, Perlis, Malaysia)

Abstract: Machining process involves many process parameters. Achieving accurate dimensions, good surface quality, and maximized metal removal are of utmost importance. This research work describes the optimization of cutting parameters for the surface roughness in CNC turning machining with aluminum alloy 6061 material. Controlling the required surface quality is necessary. In this study, Taguchi method is used to find the optimal cutting parameters for surface roughness in turning. L-9 orthogonal array, signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in the turning operations of aluminum alloy 6061 using uncoated inserts. A precise knowledge of these optimum parameters would facilitate reduction of machining costs and improve product quality. The current study on turning process applies a response surface methodology on the most effective process parameters, namely, feed, cutting speed, and depth of cut, which are optimized considering the surface roughness and material removal rate.

Keywords: *DOE, L-9 array, material removal rate, surface roughness,Taguchi method*

I. INTRODUCTION

Surface roughness is an important measure of product quality because it greatly influences the performance of mechanical parts as well as the production cost. Surface roughness is a significant design specification of machine parts, which has a considerable effect on mechanical properties, such as wear resistance and fatigue strength. Surface quality is an important factor in evaluating machine tool productivity. Hence, achieving a consistent surface finish and tolerance is significant. Turning is the most common method for cutting and especially for finishing machined parts. In a turning operation, selecting the cutting parameters is necessary to achieve high cutting performance because cutting parameters affect surface roughness.

The best possible surface quality within the given constraints for precision component machining has been a key issue. Certain studies reveal that surface roughness is the most important requirement along with geometrical and dimensional qualities. Various parameters were found to affect the responses in many machining operations. High-speed CNC manufacturing process is chosen because of its low cost, productivity, and quality requirements. High productivity with best precision quality in manufacturing can be achieved at high cutting speed and feed rate as well as poor surface roughness. Experimental observations made on CNC machining suggest that cutting speed, feed, depth of cut, nose radius, and other factors influence surface roughness. In machining, the effects of certain factors on surface roughness have been evaluated, and models are developed to meet the requirements [2].

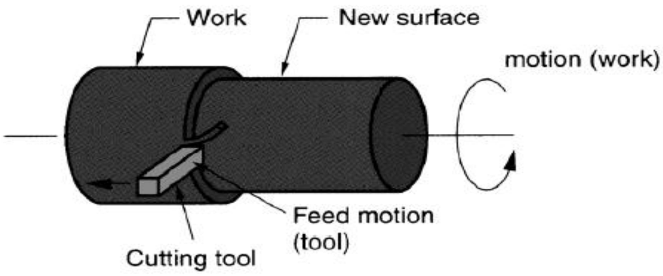

Figure 1. Cutting process

Manufacturing companies seek for a material with low surface roughness, low tool wear, and high material removal rate (MRR) to produce a good quality product at minimal cost. These three outputs are the most critical considerations in the turning process. Thus, the selection of machining parameters, such as cutting speed, feed rate, and depth of cut, is very important because they directly influence the problem. In addition, selecting machining parameters that can provide good performance for all the problems simultaneously is very difficult. Many of the parameters selected can optimize only one of the three outputs at a time. Therefore, this study determines the optimum machining parameter that can improve all three output problems simultaneously.

II. OVERVIEW OF TAGUCHI METHOD

Taguchi method is used to improve the quality of products and processes. Improved quality results when high performance levels are consistently obtained. The highest possible performance is obtained by determining the optimum combination of design factors. Performance consistency is obtained by making the product/process insensitive to the influence of the uncontrollable factors [1,3].

In Taguchi's approach, an optimum design is determined using experimental design principles, and performance consistency is achieved by carrying out trial conditions under the influence of noise factors.

2.1. Experimental objectives

- To determine the evaluation criterion and decide how each criterion is to be weighed and combined for the overall evaluation
- To identify all influencing factors and those to be included in the study
- To determine the factor levels
- To determine the noise factors and the repetition conditions [3]

2.2. Designing the experiments

The factors and levels employed are determined in a brainstorming session. The experiments are then designed, and the method of carrying them out is established. In designing the experiment, an orthogonal array is implemented as follows:

- The appropriate orthogonal array is selected.
- The factors and their interactions are assigned to columns.
- Each trial condition is described.
- The order and repetition of trial conditions is described.

1.3. Running the experiments

The experiments are run in random order whenever possible.

2.4 Result analysis

Before analysis, the experimental data have to be combined into an overall evaluation criterion. This step is particularly important when multiple evaluation criteria are analyzed to determine the following:

- Optimum design
- Influence of individual factors
- Performance at optimum conditions
- Relative influence of individual factors [4,5]

2.5 Running a confirmation experiment

Running the experiments at the optimum condition is the final step in the study.

III. ANOVA

Taguchi method is a special design of orthogonal arrays that is used to study the entire design factor space with only a small number of experiments. Among the several steps in this method, optimization of design factor is the key step to achieve the desired quality without increasing the cost. Optimization of the design factors can improve performance measurement, and the optimal design factor combinations obtained from the Taguchi method are insensitive to variations of environmental conditions and other noise factors [1,3,5].

Statistical ANOVA is performed to identify the design factors that are statistically significant. The optimal combination of the design factors can be predicted based on the result of this analysis. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

All the experimental results obtained are formulated into single indexes and then analyzed to observe the influence of the factors and determine the best design condition. Two types of information can be obtained from the analyzed results:

a) Simple arithmetic calculation
- Average factor effect (main effect)
- Optimum condition
- Estimated performance at optimum conditions

b) Statistical calculation
- Relative influence of the factors (percentage)
- Confidence interval on optimum performance
- Test of significance of the factors' influence

This work focuses mainly on the estimation of optimum conditions. Thus, the most significant calculations are those in type a. Calculation of the relative influence of the factors is also carried out to obtain the percentage of the factors' influence [6,7,8].

IV. EXPERIMENTAL SETUP

The material work pieces used in this work come in standard sizes (60 mm × 10 mm). A CNC turning lathe machine (FCL-608) with a diameter limit of 100 mm and a maximum length of 200 mm is used. A spindle with 1 HP, 100 rpm to 6000 rpm spindle speed, 32 mm maximum turning diameter, and 1.2 m/min rapid traverse rate is employed.

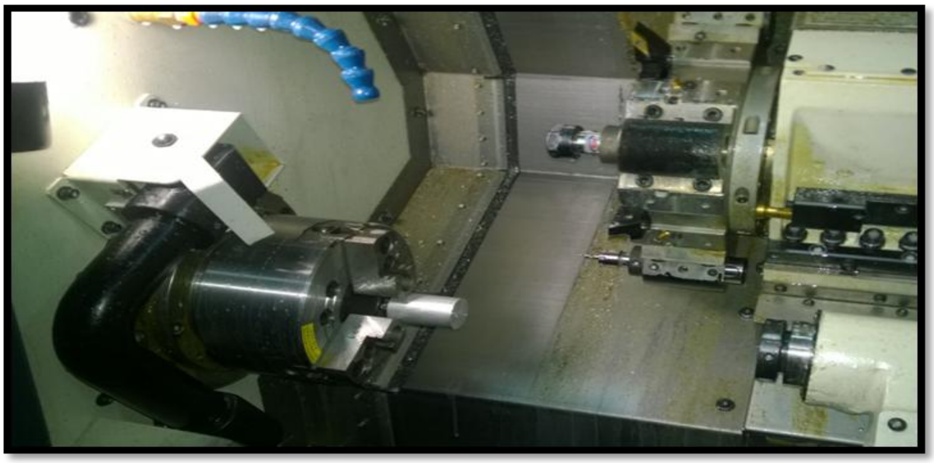

Figure 2. Cutting process in the CNC machine

In this study, three turning parameters (cutting speed, feed rate, and depth of cut) with three different levels (Table 1) are experimentally constructed for the machining operation. In Table 1, the three levels of cutting speed, feed rate, and depth of cut are identified. The parameter levels for the experiments are illustrated in Table 2.

Table 1. Design factors for aluminum alloy

Parameter Designation	Process Parameter	Level 1	Level 2	Level 3
A	Speed (rpm)	150 A3	250 A2	350 A1
B	Feed Rate (mm/rev)	0.12 B3	0.16 B2	0.20 B1
C	Depth of Cut (mm)	0.4 C3	0.6 C2	0.8 C1

Table 2. Orthogonal arrays for the three parameter levels

Experiment No.	Parameter		
	A (Speed)	B (Depth of Cut)	C (Feed Rate)
1	Level 1	Level 1	Level 1
2	Level 1	Level 2	Level 2
3	Level 1	Level 3	Level 3
4	Level 2	Level 1	Level 2
5	Level 2	Level 2	Level 3
6	Level 2	Level 3	Level 1
7	Level 3	Level 1	Level 3
8	Level 3	Level 2	Level 1
9	Level 3	Level 3	Level 2

Table 3. Experimental layout using L-9 orthogonal array

Experiment No.	Process Parameter Levels		
	A	B	C
	Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	150	0.12	0.4
2	150	0.16	0.6
3	150	0.20	0.8
4	250	0.12	0.6
5	250	0.16	0.8
6	250	0.20	0.4
7	350	0.12	0.8
8	350	0.16	0.4
9	350	0.20	0.6

Observations and Results: As previously discussed, three levels each of the input parameters speed, feed rate, and depth of cut are obtained, and the experimental layout of the three parameters using the L-9 orthogonal array is formed, as shown in Table 5.

Nine experiments are conducted for the abovementioned sets of parameters (speed, feed rate, and depth of cut), and in each experiment, surface roughness and MRR are evaluated.

Table 4. Experimental results for surface roughness in quality characteristics MSD and S/N

Experiment No.	Factor			Surface Roughness (Ra)			
	Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)	Minitab (µm)	Actual (µm)	Error%	S/N
1	150	0.20	0.4	0.342	0.358	4.7*	8.15
2	150	0.16	0.6	0.261	0.284	8.8	10.8
3	150	0.12	0.8	0.237	0.256	8.02	21.7
4	250	0.20	0.6	1.201	1.148	4.4*	1.27
5	250	0.16	0.8	0.891	0.995	11.6	0.09
6	250	0.12	0.4	1.109	1.214	9.46	1.85
7	350	0.20	0.8	1.442	1.588	10.1	4.26
8	350	0.16	0.4	1.198	1.333	11.3	2.45
9	350	0.12	0.6	1.375	1.237	10. *	1.93

Table 5. Experimental results for MRR in quality characteristics MSD and S/N

Experiment No.	Factor			Material Removal Rate			
	Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)	Minitab (Mm^3/s)	Actual (Mm^3/s)	Error%	S/N
1	150	0.20	0.4	1.210	1.0193	14**	0.166
2	150	0.16	0.6	4.899	4.5537	7	13.17
3	150	0.12	0.8	7.801	8.0856	3.7	18.15
4	250	0.20	0.6	10.9904	9.4567	13	19.52
5	250	0.16	0.8	5.0120	4.3573	13**	12.78
6	250	0.12	0.4	4.6302	4.9684	7.3	13.92
7	350	0.20	0.8	2.0109	2.2046	9.7	6.867
8	350	0.16	0.4	13.986	12.597	9.9	22.00
9	350	0.12	0.6	23.202	20.316	12**	26.16

Tables 4 and 5 show the surface roughness and MRR, respectively; * denotes the optimal parameter for surface roughness (the smallest is the best); ** denotes the optimal parameter for MRR (the largest is the best).

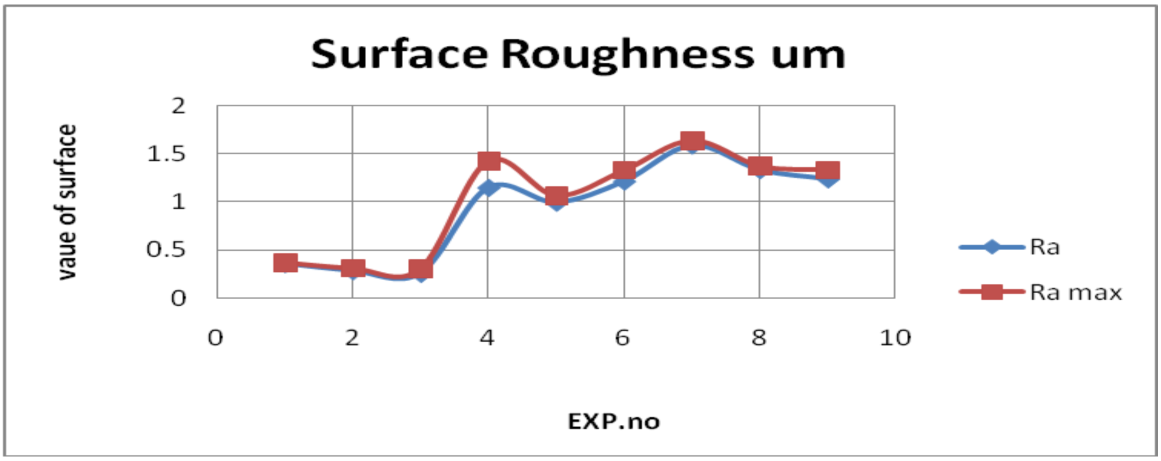

Figure 3. Relationship between Ra and maximum Ra

Fig. 3 shows the relationship between the Ra values and the maximum Ra, demonstrating variations in surface roughness and maximum surface roughness.

Design Factor	Total Sum of Squares (ST)	Pure Sum (S')	Percentage (P, %)
Speed (rpm)	512	99	31.3%
Feed Rate (mm/rev)		180	45%
Depth of Cut (mm)		124	23.5%

Table 6. ANOVA for Ra

Exp.	QC = S	
	S/N	S/N^2
1	8.15	66.4225
2	10.8	116.64
3	21.7	470.89
4	1.27	1.6129
5	0.09	0.0081
6	1.85	3.4225
7	4.26	19.8025
8	2.45	6.0025
9	1.93	3.7249
1	T	53
2	T^2	2757
3	CF	307
4	$\sum Yi^2$	688
5	ST	382
6	SA	274
7	PA	77.6
8	SB	34
9	PB	9.4
10	SC	38
11	PC	12.97

Table 7. ANOVA for MRR

Exp.	QC = B	
	S/N	S/N^2
1	0.166	0.0276
2	13.17	173.44
3	18.15	329.423
4	19.52	381.030
5	12.78	163.328
6	13.92	176.624
7	6.867	47.156
8	22.00	484.00
9	26.16	684.346
1	T	134
2	T^2	17763
3	CF	1979
4	$\sum Yi^2$	2486
5	ST	512
6	SA	99
7	PA	31.3
8	SB	180
9	PB	45
10	SC	124
11	PC	23.5

Based on the ANOVA results in Tables 6 and 7, the important information that can be obtained is the percentage influence of all factors over response. For surface roughness and MRR, ANOVA is used in comparative experiments to determine the difference in outcomes. The statistical significance of the experiment is determined by the ratio of two variances. This ratio is independent of the observations

Table 8. ANOVA for surface roughness

Design Factor	Total Sum of Squares (ST)	Pure Sum (S')	Percentage (P, %)
Speed (rpm)	382	274	77.6%
Feed Rate (mm/rev)		34	9.4%
Depth of Cut (mm)		38	12.97%

Table 9. ANOVA for MRR

This step is performed to find out more about all the terms in the table and their variances obtained by ANOVA. The factor influences are tested for significance. In addition, the factors pooled based on this significance test and the effects of the optimum conditions are also studied.

V. ANALYSIS AND DISCUSSION

From the planning phase, this study aims to determine the best combination of parameters as design factors to achieve optimum performance. Thus, the Taguchi approach experimental design is used. The optimum conditions and values are calculated using L-9 experimental design template in Microsoft Excel.

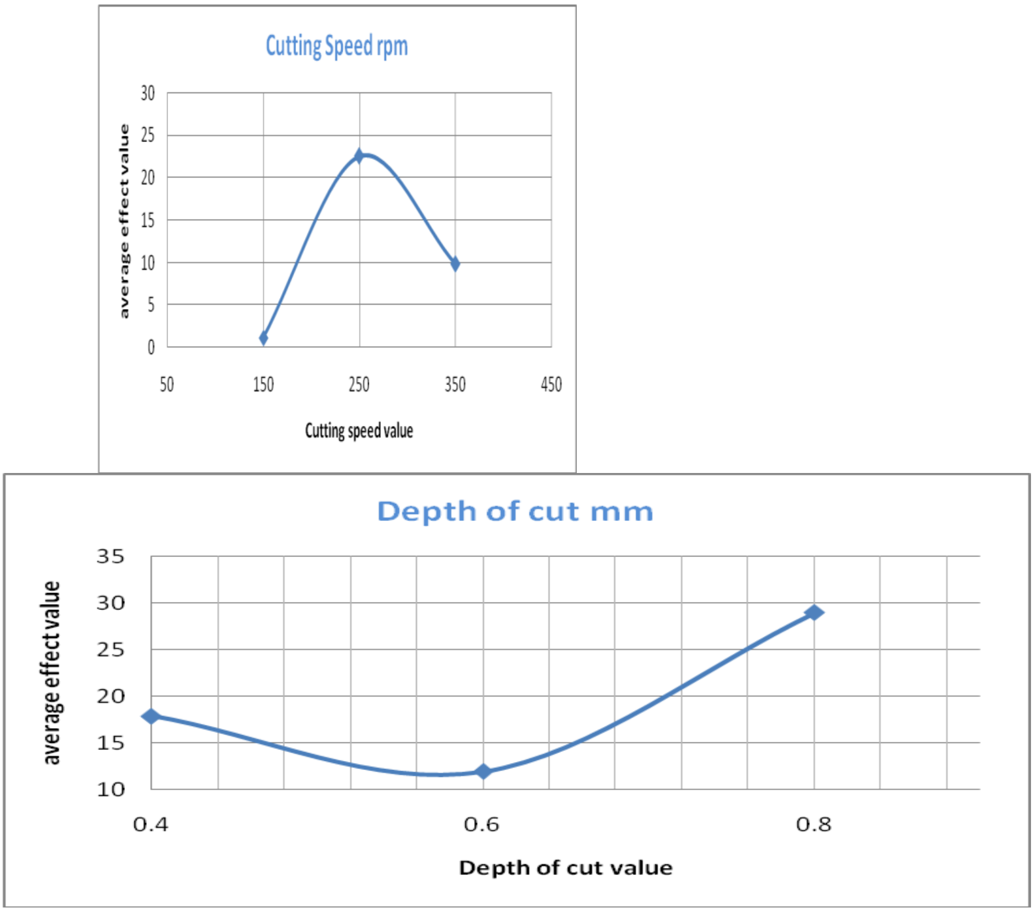

Figure 4. Graphs of cutting speed, feed rate, and depth of cut for MRR

Fig. 4 shows the relationship of speed, feed rate, and depth of cut with MRR value. The X-axis presents the variable parameters, and the Y-axis presents the average effect of the factors.

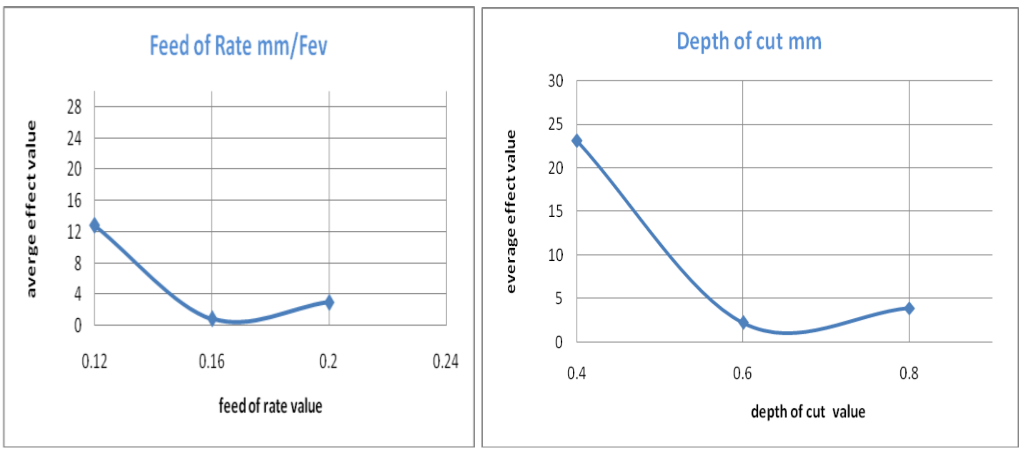

Figure 5. Graphs of cutting speed, feed rate, and depth of cut for Ra

Fig. 5 shows the relationship of speed, feed rate, and depth of cut with Ra value. The X-axis presents the variable parameters, and the Y-axis presents the average effect of the factors.

The effects of machining parameters on MRR and surface roughness in the turning process have been widely investigated by previous researchers. According to Qian and Hosan (2009), the cutting force and feed force increase with increasing feed and work piece hardness. Cutting force and feed force also increase linearly with the depth of cut. According to Jaharah et al. (2009a), the Ra produced is significantly affected by feed rate, followed by the cutting speed and depth of cut where the contribution of feed rate, cutting speed, and depth of cut were 45%, 32%, and 23%, respectively. Ghani et al. (2012) found that the surface finish of a work piece is not influenced by the tool wear; however, increasing cutting speed, feed rate, or depth of cut affects the surface finish. Tool performance was evaluated with regard to tool wear, surface finish produced, and cutting forces generated during turning (Yigit et al., 2008; Jaharah et al., 2009b) [9,10,12,13].

VI. CONFIRMATION TEST FOR MRR AND RA

Confirmation test was conducted to validate the settings that were obtained from the analysis. All three factors analyzed with the condition of the response were needed to predict the best results in the experiment. In this work, MRR and surface roughness were set to be at maximum and minimum, respectively [14]. Based on the analysis, the best setting for the cutting parameters would predict the values for the MRR and the Ra. After obtaining the optimum setting, the confirmation test was carried out. Fig. 6 and Fig. 7 show the results of the confirmation test.

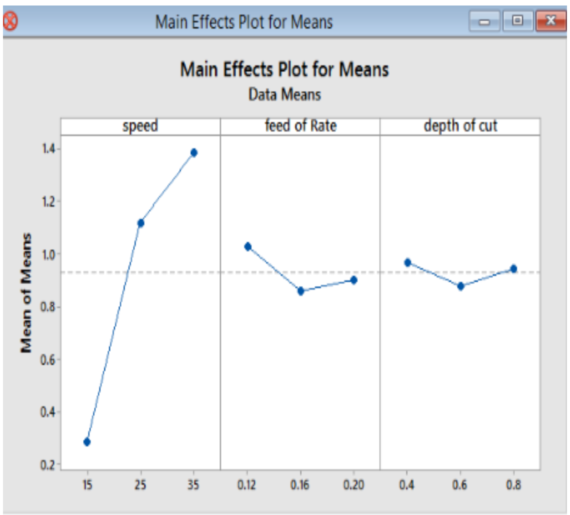

Figure 6. Main effect of factors on Ra

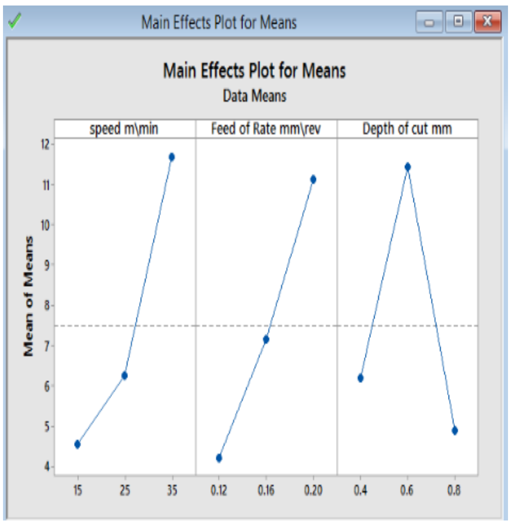

Figure 7. Main effect of factors on MRR

The cutting parameters discussed in this study are the cutting speed, feed rate, and depth of cut. The result showed that in most of the cases, surface roughness decreases with increasing cutting speed and with decreasing feed and depth of cut.

Based on the surface roughness results, the most significant factor in the cutting process is that with a percentage difference below 10%. Feed rate affects both MRR and surface roughness. The effect of cutting speed in the cutting process is more significant on surface roughness than on MRR. Faster cutting speed applied results in better surface roughness, and this finding can be explained along with other significant parameters. The depth of cut also influences both MRR and surface roughness in the cutting process.

Based on MRR, the increase in cutting speed, depth of cut, and feed rate is significant with a percentage difference below 14%. Theoretically, the cutting process causes a major effect on MRR of aluminum alloy with all three factors.

VII. CONCLUSION

A parameter design that used the Taguchi method is a simple, systematic, and efficient methodology for the optimization of process parameters [15]. Based on the results obtained in this study, the following can be concluded: the Taguchi optimization method was applied to find the optimal process parameters, which maximized MRR and minimized the surface roughness (Ra) during the cutting process. Taguchi orthogonal array, S/N ratio, and ANOVA were used for the optimization of the cutting parameters. ANOVA results show that feed rate, cutting speed, and depth of cut affect the MRR and surface roughness. A confirmation experiment was conducted and verified the effectiveness of the Taguchi optimization method. For optimal condition in surface roughness, the following results are obtained:

a) The percentage contribution of surface roughness is maximum at 11.6% and minimum at 4.4%.
b) The percentage contribution of MRR is maximum at 14% and minimum at 3.7%.
c) The percentage contributions of the effect of cutting speed, feed rate, and depth of cut are 45%, 36%, and 19%, and that of error is 4.4% for the minimum value of surface roughness.
d) The optimum combination of the parameters and their levels for obtaining minimum surface roughness is 6061 alloy.
e) Based on the aforementioned combinations, the surface roughness and dimensional tolerance were minimum at 6061 alloy with Ra value of 0.256 microns and standard deviation of 0.0063 microns.
f) The initial values of surface roughness and standard deviation that were obtained by Taguchi technique were 1.98 and 2.10862 microns, respectively. The final values of surface roughness and standard deviation that were obtained using the optimal parameters as suggested in the work were 0.256 and 0.0063 microns, respectively.

REFERENCES

[1] Ranganath M S [*], Vipin, R S Mishra(2014), *Optimization of Surface Roughness and Material Removal Rate on Conventional Dry Turning of Aluminium (6061)*, International Journal of Advance Research and Innovation Volume 1 (2014) 62-71
[2] Hardik B. Patel Satyam P. Patel (2013), *A Review Paper for Optimization of Surface Roughness and MRR in CNC Milling International Journal of Research in Modern Engineering and Emerging Technology*
[3] Montgomery, D.C., 1997, Design and analysis of experiments. 4th ed. New York: Wiley.
[4] Fisher, R.A., 1999, Statistical methods for research worker. London: Oliver & Boyd.
[5] Nian, C.Y., Yang, W.H., Tarng, Y.S., 1999, Optimization of turning operations with multiple performance characteristics. J Mater Process Technology Vol.95, pp. 90–6.
[6] Taguchi, G., 1990, Introduction to quality engineering. Tokyo: Asian Productivity Organization, Chap. 1.
H. Yanda, J. A. Ghani, M. N. A. M. Rodzi, K. Othman, C.H.C. Haron, “Optimization of Material Removal Rate, Surface Roughness and Tool Life on Conventional Dry Turning Of FCD700”, International Journal of Mechanical and Materials Engineering, 5(2), 182-190, 2010
[8] *Aluminium 6061 Properties* http://www.aalco.co.uk/datasheets/Aluminiu m-Alloy-6061-T6-Extrusions_145.ashx
[9] Marinković Velibor, Madić Miloš, “Optimization of Surface Roughness in Turning Alloy Steel by Using Taguchi Method”, Scientific Research and Essays, 6(16), Pp. 3474-3484, 19 August, 2011, ISSN 1992-2248 ©2011 Academic Journals .

[10] Ranganath M S, Vipin, R S Mishra, "Optimization Of Process Parameters In Turning Operation Of Aluminium (6061) With Cemented Carbide Inserts Using Taguchi Method And ANOVA", International Journal of Advance Research and Innovation Website: www.ijari.org ISSN 2347-3258, 1(1), 16-28,2013

[11] M. Kurt, E. Bagci, Y. Kaynal, 2009. App. of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes, Int. Journal Advanced Manufacturing Technology, 40, 458-469

[12] Jitendra Verma, Pankaj Agrawal, Lokesh Bajpai, "Turning Parameter Optimization for Surface Roughness of Astm A242 Type-1 Alloys Steel by Taguchi Method", International Journal of Advances in Engineering & Technology, March, ©IJAET ISSN: 2231-1963, 255 3(1), Pp. 55-261, 2012

[13] Ilhan Asiltürk, Harun Akkus, 2011. '*Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method*' Measurement 44 (2011) 1697–1704

[14] Davim, J. Paulo, Gaitonde, V.N., Karnik, S.R., 2008, Investigations into the effect of cutting conditions on surface roughness in turning of free machining steel by ANN models, journal of materials processing technology Vol. 205, pp. 16–23.

[15] Prof. (Dr). Rachayya.R.Arakerimath and Prof (Dr).V.A.Raikar, "Productivity Improvement by Sa and Ga Based Multi-Objective Optimization in CNC Machining" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 1, 2012, pp. 100 - 109, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359

(Email: Eng_ali_S@hotmail.com) [1] *(Email: bhuvenesh@unimap.edu.my)* [2] *(Email: nasser1256@yahoo.uk)* [3]