# INFLUENCES AND OPTIMIZATION OF CNC TURNING MACHINING PARAMETERS

**Shukry H. Aghdeab**
**Production Engineering and Metallurgy Department, University of Technology/ Baghdad**
**shukry_hammed@yahoo.com**

**Baqer Ayad Ahmed**
**bakeryd@yahoo.com**

**Mohammed Sattar Jabbar**
**mohammedsattar43@yahoo.com**

**Asaad Ali Abbas**
**asaad.ali.abbas@gmail.com**

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## ABSTRACT

In this study, the objective is to obtain optimal values of CNC turning parameters (cutting speed, depth of cut and feed rate) which result in an optimal value of surface roughness by machining aluminum shaft. In this work, Taguchi method was carried out on machining of aluminum ENAC-43400 material in dry cutting using CNC turning machine type StarChip 450 equip with carbide cutting tool type DNMG 332. Surface roughness was measured using the POCKET SURF EMD-1500 tester. The results obtained of the surface roughness (Ra) are about (1.14-1.91) μm, and the best was at cutting speed 250 m/min, feed rate 0.05 mm/rev and depth of cut 0.5 mm which is refers to the optimum machining parameters.

**Keywords:** CNC turning process, surface roughness, machining parameters, optimization, Taguchi method.

# تأثير وأمثلية محددات التشغيل على ماكنة الخراطة المبرمجة

**الخلاصة**

في هذه الدراسة, الهدف هو الحصول على القيم المثلى لمحددات التشغيل لماكنة الخراطة المبرمجة (سرعة القطع, عمق القطع والتغذية) كنتيجة لقيم مثلى من الخشونة السطحية بتشغيل قضيب من الألمنيوم ENAC-43400. في هذا العمل, تم استخدام طريقة تاكوجي في عملية تشغيل سبيكة الألمنيوم في ماكنة الخراطة نوع StarChip 450 باستخدام عدة قطع كاربيدية نوع DNMG 332 والخشونة السطحية تم قياسها باستخدام POCKET SURF EMD-1500 tester . النتائج التي تم الحصول عليها للخشونة السطحية (Ra) كانت بحدود (1.91-1.14) مايكرومتر, وافضلها عند ( سرعة القطع 250 متر/دقيقة, وتغذية 0.05 ملم/دورة، وعمق قطع 0.5 ملم) والتي تشير الى متغيرات التشغيل المثلى.

## INTRODUCTION

A surface manufactured by cutting processes is one of the most important criteria for quality. Surface roughness is a significant factor which is not only important for wear, friction and lubrication which became traditional for tribology, but also important for sealing, hydrodynamic, electric and heat transfer. Surface roughness depends on lots of variable such as material couple, manufacturing type, cutting conditions and etc. Surface roughness is one of the most important characteristic variable to be monitored in the cutting processes owing to the direct relation between change of surface roughness and cutting conditions (Ilhan, 2010).

In machining operation, the surface finish is an important requirement of workpieces and parameter in manufacturing engineering. During the turning operation, the cutting tool and the metal bar are subjected to a prescribed deformation as a result of the relative motion between the tool and workpiece both in the cutting speed direction. As a response to the prescribed deformation, the tool is subjected to thermal loads on those faces that have interfacial contact with the workpiece or chip. In the metal-cutting process, during which chips are formed, the workpiece material is compressed and subjected to plastic deformation. Usually the material removal occurs in a highly hostile environment with high temperature and pressure, in the cutting zone. The ultimate objective of the science of metal cutting is to solve practical problems associated with efficient material removal in the metal cutting process. To achieve this, the principle governing the cutting process should be understood. Knowledge of this principle predicts the practical result of the cutting process and thus the select the optimum cutting conditions for each particular case (Rakesh, 2012).

The literature survey has revealed that several researchers attempted to calculate the optimal cutting conditions in turning operations.

Basim A. Khidhir and Bashir Mohamed (2011) studied the effect of cutting speed, feed rate and depth of cut on surface roughness. The tests were performed on Nickel based Hastelloy C-276 using two different inserts of ceramic cutting tools. It has been found that the good surface roughness is obtain with higher cutting speed, minimum feed rate and lower depth of cut.

Anil Gupta and et al (2010) studied the effect of cutting speed, feed rate, depth of cut, nose radius and cutting environment on surface roughness, tool life, cutting force and power consumption. It have been found that cutting speed of 160 m/min, nose radius of 0.8 mm, feed of 0.1 mm/rev, depth of cut of 0.2 mm and the cryogenic environment are the most favorable cutting parameters for high speed CNC turning of AISI P-20 too1 steel.

Ilhan Asiltürk and Mehmet Çunkas (2011) studied the effect of cutting speed, feed rate, depth of cut on surface roughness of AISI 1040 steel. It have been implemented full factorial experimental design to increase the confidence limit and reliability of the experimental data, Artificial neural networks (ANN) and multiple regression approaches, it have been compare multiple regression and neural network using statistical methods. It has been found that the proposed models are capable of prediction of the surface roughness. The ANN model estimates the surface roughness with high accuracy compared to the multiple regression model.

Attanasio and et al (2011) have been investigation a series of orthogonal hard turning tests were conducted to study the effects of tool wear and cutting parameters (cutting speed and feed rate), on white and dark layer formation in hardened AISI 52100 bearing steel. It has been found that the crater wear rate is influenced by both cutting speed and feed rate, while flank wear rate seemed to be mainly effected by cutting speed. Also it was found that the thickness of white and dark layers increases with increasing of tool flank wear. Moreover higher cutting speed generates thicker white layers and thinner dark layers. In addition, smaller feed rates moderately influence the white layers thickness, while the latter rises with higher feed rate. In Contrast, the dark layers thickness decreases with the increasing of the feed rate, especially when flank wear values higher 0.075 mm were observed.

Ilhan Asiltürk and Süleyman Neseli (2012) have been determine the effect of cutting parameters namely, cutting speed, depth of cut and feed rate on surface roughness during machining of AISI 304 austenitic stainless. The model for the surface roughness, as a function of cutting parameters, is obtained using the response surface methodology (RSM). It have been found that the feed rate is the dominant factor affecting surface roughness, which is minimized when the feed rate and depth of cut are set to the lowest level, while the cutting speed is set to the highest level. The percentages of error all fall within 1%, between the predicted values and the experimental values.

Suleyman Neseli and et al (2011) have been investigated the effect of tool geometry parameters on the surface roughness during turning of AISI 1040 steel. It has been developed prediction model related to average surface roughness (Ra) using experimental data. It has been found that the tool nose radius was the dominant factor on the surface roughness with 51.45% contribution in the total variability of model. Also, approach angle and rake angle are significant factors on surface roughness with 18.24% and 17.74% contribution in the total variability of model, respectively. In addition, a good agreement between the predicted and measured surface roughness was observed.

H. K. Dave and et al (2012) have been investigated the machining characteristics of different grades of EN materials in CNC turning process using Tin coated cutting tools. In this research focused on the analysis of optimum cutting conditions to get the lowest surface roughness and maximum material removal rate (MRR) in CNC turning of different grades of EN materials by Taguchi method. It have been found that ANOVA shown that the depth of cut has significant role to play in producing higher MRR and insert has significant role to play for production lower surface roughness. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment. Were minimum surface roughness when machined by CN1500 tool at 150 m/min speed, 0.30 mm/rev feed and 1 mm depth of cut and maximum MRR when machined by CC8020 tool at 150 m/min speed, 0.30 mm/rev feed and 1.5 mm depth of cut.

M. Kaladhar and et al (2012) have been investing the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of these process parameters. And the Analysis of Variance (ANOVA) is also used to analyze the influence of cutting parameters during machining. It have been found that the feed and nose radius is the most significant process parameters on workpiece surface roughness. However, the depth of cut and feed are the significant factors on MRR. Optimal range and optimal level of parameters are also predicted for responses. The optimal combination of process parameters for minimum surface roughness is obtained at 150 m/min cutting speed, 0.25 mm/rev feed rate, 2 mm depth of cut and 0.4 mm nose radius. And the optimal combination of process parameters for maximum MRR is obtained at 170 m/min cutting speed, 0.3 mm/rev feed rate, 2mm depth of cut and 0.4mm/0.8mm nose radius.

Anderson P. Paiva and et al (2007) have been conduct experiment on AISI 52100 hardened steel with different parameter (cutting speed, feed rate and depth of cut). The outputs considered were (the mixed ceramic tool life, processing cost per piece, cutting time, the total turning cycle time, surface roughness and material removal rate). The results indicate that the multi response optimization is achieved at a cutting speed of 238 m/min, with a feed rate of 0.08 mm/rev and at a depth of cut 0.32 mm.

Tian Syung Lan (2010) have been investigate the effect of cutting speed, feed rate, cutting depth and tool nose runoff with three levels (low, medium, high) MRR in finish turning based on Fuzzy L9(34) orthogonal array. It have been found that the material removal rates from the fuzzy Taguchi deduction optimization parameters are all significantly advanced comparing to those from the benchmark. Also it has been declare that contributed the satisfactory fuzzy linguistic approach for the MRR in CNC turning with profound insight. It is observed that the MRR under fuzzy deduction parameters are significantly improved by 87.5, 150.0 and 212.5% from the benchmark parameters.

Hussam Lefta Alwan (2013) have been investigated the effect of machining conditions in turning of Al-12%Si alloy to get lowest surface roughness by applying the Taguchi method. The percent contribution of the significant factor produced from analysis of variance ANOVA is 53.14 %. This is, for this case study, the depth of cut has the highest contribution; therefore, the depth of cut is an important factor to be taken into consideration during machining Al-12%Si alloy followed by feed rate, and cutting speed respectively.

## TAGUCHI METHOD

Traditional experimental design procedures are too complicated, very expensive and not easy to use. A large number of experimental works has to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments (Małgorzata, 2014). Taguchi method, widely utilized in engineering analysis, consists of a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behavior of a given process. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost and discovering significant factors quickly (Rama, 2012). Taguchi design experiments using specially constructed tables known as "orthogonal array" (OA). The use of these tables makes the design of experiments very easy, consistent and required relatively lesser number of experimental trials to study the entire parameter space. As a result, time, cost, and labor saving can be achieved. The experimental results are transformed to signal -to- noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis (P.G.Kochure, 2012).

The signal-noise [S/N] ratio is calculated from applying equations (Raviraj, 2008):

**i)** For the "smaller is better" the equation is:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

**ii)** For the "larger is better" the equation is:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \qquad (2)$$

Where:

S/N = The signal-noise ratio

n= The number of observations

$y_i$ = The observed data.

For our study the "the smaller is better" was used because smaller values of surface roughness means high quality of machined surface.

## EXPERIMENTAL VERIFICATIONS

Many factors (cutting speed, feed rate and depth of cut) effect on the surface roughness in CNC turning process. The experiments were conducted on CNC lathe type StarChip 450 by using carbide cutting tool type DNMG 332, as shown in **Fig.1**.

The work material used in this research is Aluminum ENAC-43400 shaft. The diameter of the material is 46 mm and length is 150 mm. The chemical composition of work piece material was done by spectrometer device in the Central Organization for Standardization and Quality Control and is given in **Table1**, and mechanical properties of this work material shown in **table 2**. The surface roughness (Ra) was measured by the POCKET SURF EMD-1500 tester, as shown in **Fig.2**.

The workpiece was mounted using a pneumatic chuck in CNC lathe center and the clamping pressure was set as (8) bar. The machining parameters like cutting speed, feed rate and depth of cut were selected based on the manufacturer's recommendations. Experiments were conducted by varying the cutting parameters and the surface roughness values were measured using automatic digital POCKET SURF EMD-1500 test.

The tests were performed on a CNC lathe. The aluminum workpiece with dimensions of shaft diameter 46 mm and length of 150 mm was clamped in the turret of the CNC machine table. A computer numerical control program was written to perform the turning process. The parameters defined in the turning machine were cutting speed (m/min), feed rate (mm/rev) and depth of cut (mm). The Taguchi $L_9$ orthogonal array were selected. The machining controllable: cutting speed, feed rate, and depth of cut parameters were depended (A, B, and C) and their levels are shown in **table 3**.The $L_9$ orthogonal array with three columns and nine rows was suitable for use in this research. The controllable machining parameters and levels for surface roughness are arranged as shown in **table 4** were each row represents an experiment with different combination of machining parameters and their levels.

## RESULTS AND DISCUSSION

The turning experiments were conducted and the readings of surface roughness and signal -to-noise ratio (S/N) are given in **table 5**. The S/N ratio must be smaller as possible, therefore the quality characteristic "smaller is better" was used. Then the results were analyzed depending on main effect for both surface roughness (Ra) and signal to noise ratio (S/N) and the ANOVA analysis. The average values of surface roughness and (S/N) ratio are determined for the controllable machining parameters (A, B and C) at each level as shown in **table 6** and **table 7** respectively. The values in **table 6** are represents the average of surface roughness, for example level1 is represent the three experiments 1,2 and 3 in **table 5** and computed as the mean of them:

- Cutting speed (A) = (1.33+1.71+1.91)/3=1.65.
- Feed rate (B) = (1.33+1.41+1.41)/3=1.383.
- Depth of cut (C) = (1.33+1.36+1.14)/3=1.277.

Also for the level 2 are computed as follow:

- Cutting speed (A) = (1.41+1.63+1.36)/3=1.467.
- Feed rate (B) = (1.71+1.63+1.14)/3=1.493.
- Depth of cut (C) = (1.71+1.41+1.34)/3=1.487.

Similarly for level three:

- Cutting speed (A) =1.297.
- Feed rate (B) =1.537.
- Depth of cut (C) =1.65.

The Delta values that shown in the **table 6** are represented the difference between the maximum and minimum mean response across levels of a factor (the overall change in a value).

The graph that shown in **Fig.3** and **Fig.4** shows the main effect for surface roughness and S/N ratio. The best (smaller is better) surface roughness is obtained from the combination of controllable machining parameters A3,B1 and C1 (cutting speed 250m/min, feed rate 0.05 mm/rev and depth of cut 0.5 mm) which is refers to the optimum machining parameters. Also the analysis of variance (ANOVA) was performed using Taguchi method in Minitab 17 software as shown in **table 8**.

From this table the contribution of each machining parameters was computed, depth of cut (47.727%) which represents the most influences machining parameters when machining this type of aluminum alloy (ENAC-43400), followed by cutting speed (42.500%) and last influences machining parameters is feed rate were its contribution rate was (8.409%). Then a predicated surface roughness also made with using optimum controllable machining parameters were its value was( Ra=1.014μm) by Minitab 17 software

## CONCLUSION:

The main conclusions which can be deduced from this research can be summarized as follows:

**1**- The surface roughness (Ra) in this work is about (1.14-1.91μm).

**2-** The best surface roughness was obtained from the combination of controllable machining parameters A3,B1 and C1 (cutting speed 250 m/min, feed rate 0.05 mm/rev and depth of cut 0.5 mm) which is refers to the optimum machining parameters.

**3-** The contribution percentage of depth of cut (47.727%), followed by cutting speed (42.500%) and feed rate was (8.409%) when machining aluminum alloy ENAC-43400.

## REFERENCES

[1] Anderson P. Paiva and et al (2007) “A multivariate hybrid approach applied to AISI 52100 hardened steel turning optimization”, Journal of Materials Processing Technology, 189, 26-35.

[2] Anil Gupta and et al (2011) “Taguchi-fuzzy multi output optimization (MOO) in high speed CNC truing of AISI P-20 tool steel”, Expert System with Application, 6822-6828,.

[3] Attanasio and et al, (2011) “Study the effects of tool wear and cutting parameters on white and dark layer formation in hardened AISI 52100 bearing steel”.

[4] Basim A. Khidhir and Bashir Mohamed (2011) “Analyzing the effect of cutting parameters on surface roughness and tool wear when machining nickel based hastelloy-276” IOP Publishing,.

[5] H. K. Dava, L. S. Patel, H. K. Raval, (2012) “Effect of machining conditions on MRR and Surface Roughness during CNC Turning of different Materials Using TiN Coated Cutting Tools- A Taguchi approach”, International Journal of Industrial Engineering Computations 3.

[6] Hussam L. Alwan (2013)" Determination the Optimal Cutting Conditions Affecting the Surface Roughness Using TaguchiI Method in Turning (AL-12%SI) by Carbide Tool" The Iraqi Journal For Mechanical And Material Engineering, Vol.13, No.2.

[7] Ilhan and Ali., (2010)″Development of a Neural Network Based Surface Roughness Prediction System using Cutting Parameters and an Accelerometer in Turning″, Department of Mechanical Education, Faculty of Technical Education, University of Seljuk, Turkey, IEEE.

[8] Ilhan Asiltürk and Mehmet Çunkas, (2011) “Modeling and predication of Surface Roughness in truing operations using artificial neural network and multiple regression method”, Expert System with Applications 38, 5826-5832.

[9] Ilhan Asiltürk and Süleyman Neseli, (2012) “Multi response optimization of CNC turning parameters via Taguchi method based response surface analysis”, Measurement Volume 45, Issue 4.

[10] M. Kaladhar and et al (2012) “Determination of Optimum Process parameters during turning of AISI 304 Austenitic Stainless Steel using Taguchi method and ANOVA “International Journal of lean thinking, volume 3, issue 1.

[11] Małgorzata Kowalczyk (2014) "Application of Taguchi and ANOVA Methods in Selection of Process Parameters for Surface Roughness in Precision Turning of Titanium" advanced in manufacturing science and technology,Vol. 38, No. 2.

[12] P.G.Kochure, K.N.Nandurkar (2012) "Taguchi method and ANOVA: An approach for selection of process parameters of induction hardening of EN8 D steel" International Journal of Advance Research in Science, Engineering and Technology, Vol.01, Issue 02, pp. 22 -27.

[13] Rakesh K. Patel and H. R. Prajapati, (2012) ,″ Parametric Analysis of Surface Roughness (SR) and Material Removal Rate (MRR) of Harden Steel on CNC Turning using ANOVA Analysis″, International Journal of Engineering Science and Technology, Vol. 4, No. 07, India.

[14] Rama Rao. S, Padmanabhan. G (2012) " Application of Taguchi methods and ANOVA in optimization of process parameters for metal removal rate in electrochemical machining of Al/5%SiC composites" International Journal of Engineering Research and Applications,vol.2, pp. 192-197.

[15] Raviraj Shetty, R. P. (2008) "Study On Surface Roughness Minimization In Turning of DRACs Using Surface Roughness Methodology And Taguchi Under Pressured Steam Jet Approach" ARPN Journal of Engineering and Applied Sciences, 3 (1), 59-67.

[16] Suleyman Neseli, Suleyman Yaldiz, Erol Turkes, (2011) “Optimization of tool geometry parameters for turning operations based on the response surface methodology”, Measurement 44 580-587.

[17] Tian Syung Lan (2010) “Fuzzy Deduction Material Removal Rate Optimization for Computer Numerical Control Turning”, American Journal of Applied Sciences, 1026-1031.

**Table (1):** Chemical composition of Al ENAC-43400 alloy.

| Element | Si | Fe | Mg | Mn | Cr | Cu | Ti | Zn | Other | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| Wt % | 10.40 | 0.72 | 0.34 | 0.21 | 0.02 | 0.1 | 0.05 | 0.15 | 0.15 | Bal. |

**Table (2):** Mechanical properties of Al ENAC-43400 alloy.

| Mechanical Properties | Al ENAC-43400 Alloy |
|---|---|
| Tensile Strength | 240 MPa |
| 0.2% Proof Strength | 140 MPa |
| Brinal Hardness N. | 70 |
| Elongation at Fracture | 1 % |
| Poisson's ratio | 0.3 |

**Table (3):** Machining parameters and their levels.

| Symbol | Machining parameters | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| A | Cutting speed | m/min | 165 | 200 | 250 |
| B | Feed rate | mm/rev | 0.05 | 0.06 | 0.07 |
| C | Depth of cut | mm | 0.5 | 0.75 | 1 |

**Table (4):** Taguchi $L_9$ Orthogonal array.

| No. of experiment | Machining parameters levels | | |
|---|---|---|---|
| | A | B | C |
| | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of cut (mm) |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

**Table (5):** Experimental Surface Roughness and S/N results.

| No. | Machining parameters | | | Ra (μm) | S/N (dB) |
|---|---|---|---|---|---|
| | A | B | C | | |
| | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of cut (mm) | | |
| 1 | 165 | 0.05 | 0. 5 | 1.33 | -2.477 |
| 2 | 165 | 0.06 | 0.75 | 1.71 | -4.659 |
| 3 | 165 | 0.07 | 1 | 1.91 | -5.620 |
| 4 | 200 | 0.05 | 0.75 | 1.41 | -2.984 |
| 5 | 200 | 0.06 | 1 | 1.63 | -4.243 |
| 6 | 200 | 0.07 | 0. 5 | 1.36 | -2.670 |
| 7 | 250 | 0.05 | 1 | 1.41 | -2.984 |
| 8 | 250 | 0.06 | 0. 5 | 1.14 | -1.131 |
| 9 | 250 | 0.07 | 0.75 | 1.34 | -2.542 |

**Table (6):** Main effect for Surface Roughness (Ra).

| Symbol | Machining parameters | Average of Ra(μm) | | | Delta (max-min) μm | Rank |
|---|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | | |
| A | Cutting speed (m/min) | 1.650 | 1.467 | 1.297 | 0.353 | 2 |
| B | Feed rate (mm/rev) | 1.383 | 1.493 | 1.537 | 0.153 | 3 |
| C | Depth of cut (mm) | 1.277 | 1.487 | 1.650 | 0.373 | 1 |

**Table (7):** Main effect for S/N ratio.

| Symbol | Machining parameters | Average of S/N(dB) | | | Delta | Rank |
|---|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | | |
| A | Cutting speed (m/min) | -4.253 | -3.300 | -2.222 | 2.031 | 2 |
| B | Feed rate (mm/rev) | -2.815 | -3.347 | -3.611 | 0.796 | 3 |
| C | Depth of cut (mm) | -2.095 | -3.395 | -4.283 | 2.188 | 1 |

**Table (8):** ANOVA table for surface roughness

| Symbol | Sum of Squares | Degrees of freedom | Mean Squares | F-value | Contribution % |
|---|---|---|---|---|---|
| A | 0.187 | 2 | 0.093 | 28.87 | 42.500 |
| B | 0.037 | 2 | 0.018 | 5.78 | 8.409 |
| C | 0.210 | 2 | 0.105 | 32.39 | 47.727 |
| E | 0.006 | 2 | 0.003 | | 1.363 |
| Total | 0.440 | 8 | | | 100 |


**Figure (1):** CNC lathe use in experimental work


**Figure (2):** Automatic digital POCKET SURF EMD-1500.

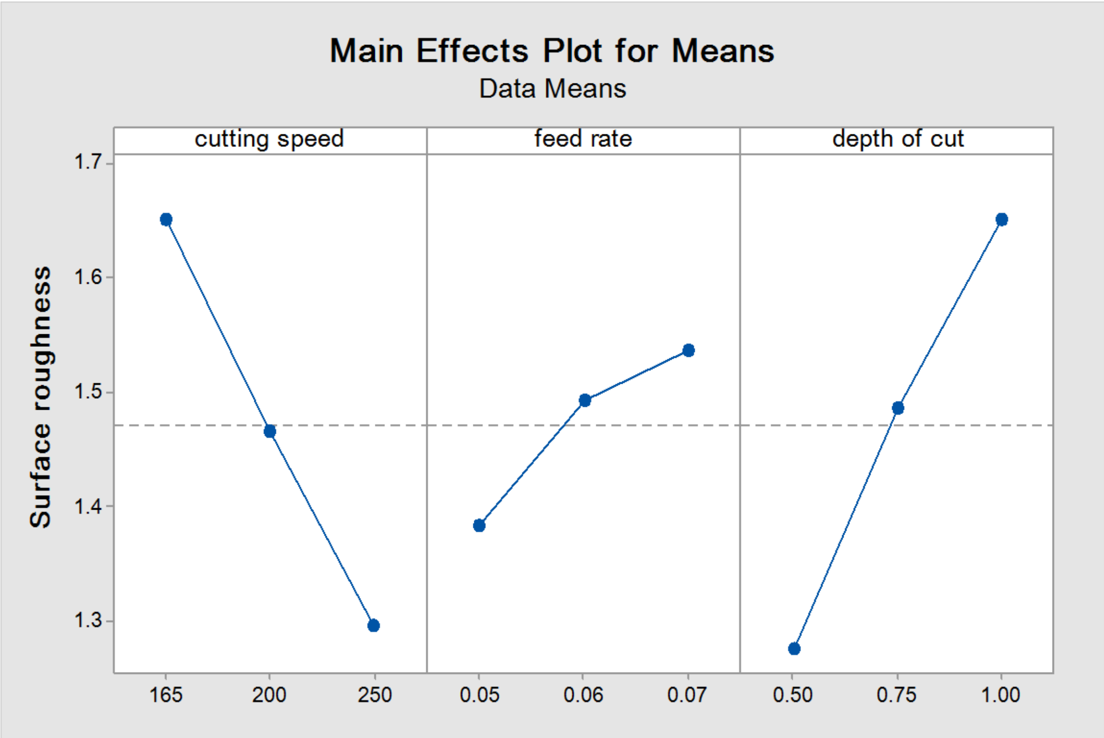


**Figure (3):** Main effect for surface roughness.

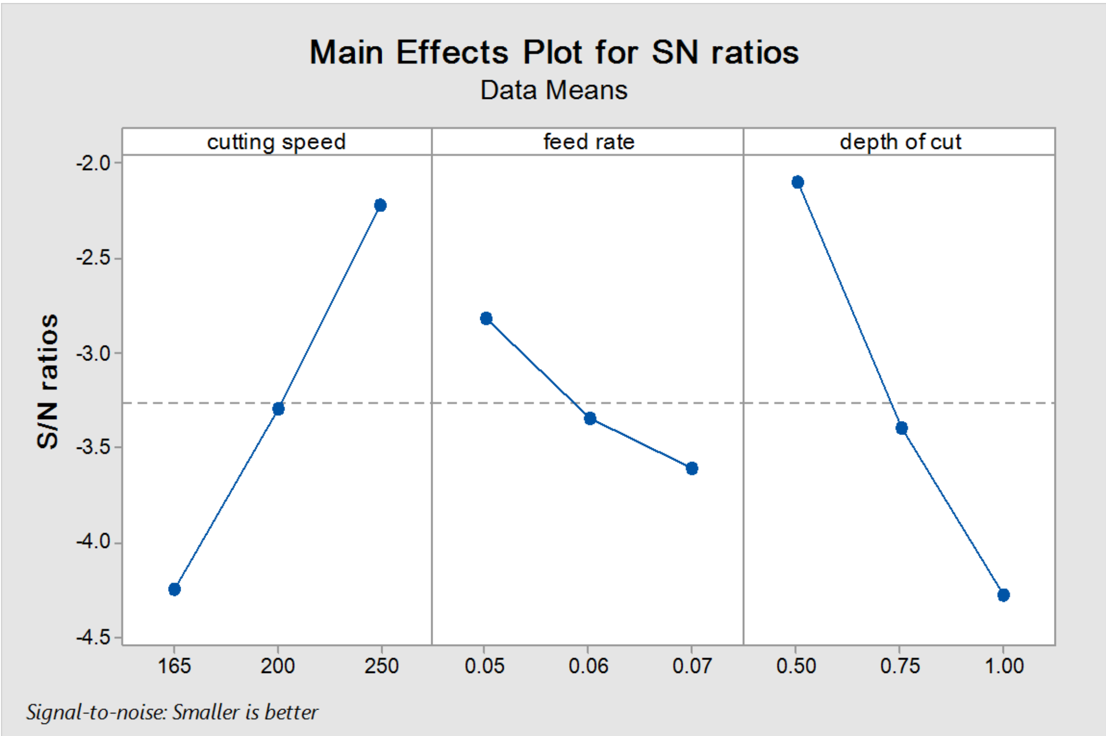


**Figure (4):** Main effect for S/N ratio.