

## STUDY THE OPTIMAL CUTTING CONDITIONS AFFECTING THE COPPER SURFACE ROUGHNESS BY TAGUCHI TECHNIQUE

Baraa Mohsen Hossien Albaghdadi

Production Engineering and Metallurgy Department, University of Technology  
Baghdad-Iraq / baraa.albaghdadi@gmail.com

### ABSTRACT

This research aims to find the optimal conditions affecting the surface roughness when copper is turned. In this work the Taguchi method is used to optimize the cutting parameters. The parameters considered here are: spindle speed, feed rate, and the tool nose radius while the depth of cut has been fixed during the experiments. The tool used for conducting the experiment is High Speed Steel (HSS). Once the surface roughness is measured, the quality characteristic "smaller is the better" is applied to calculate the signal to noise ratio S/N for each experiment. Also, by using ANOVA output, the factor that has more significant in the process has been determined depending on its percentage of contribution. The results showed that the optimum combination of levels of the parameters were (3-1-1) that are corresponding to spindle speed (1120 rpm), feed rate (0.065 mm/rev), and tool nose radius (4 mm). The significant factor that has maximum contribution according to ANOVA results is the spindle speed with 58.581% followed by feed rate and tool nose radius respectively.

**Keywords:** Surface Roughness, Turning Conditions, Taguchi Method, ANOVA and Copper.

### دراسة ظروف القطع المثلى المؤثرة على خشونة السطحية للنحاس باستخدام طريقة تاكوجي

#### الخلاصة :-

يهدف البحث الى ايجاد الظروف المثلى المؤثرة على خشونة السطحية عند تشغيل النحاس في عملية الخراطة. تم في هذا البحث استخدام طريقة تاكوجي لأيجاد الظروف المثلى لمتغيرات القطع. الظروف المستخدمة هنا هي سرعة دوران القطعة ومعدل التغذية ونصف قطر مقدمة الاداة حيث تم استخدام فولاذ القطع السريع كاداة قطع، بينما قد تم تثبيت مقدار عمق القطع. تم تطبيق الخاصية "الأصغر هو الأفضل" بالنسبة لحساب النسبة بين الاشارة الى الضوضاء (S/N) لكل تجربة. أيضا تم استخدام تحليل التباين ANOVA، في تحديد أكثر عامل مؤثر من عوامل متغيرات القطع من خلال امتلاكه لأكثر نسبة مشاركة او مساهمة في العملية. بينت النتائج بان التوليفة الامثل لمتغيرات القطع كانت عند المستويات (3-1-1) والتي تتمثل بسرعة دوران القطعة (1120 دورة في الدقيقة)، ومعدل التغذية (0.065 ملم/دورة)، ونصف قطره مقدمة الاداة (4 ملم). العامل الأكثر اهمية بحسب مساهمته الأكبر والذي بينه جدول ANOVA هو سرعة دوران القطعة بنسبة مشاركة 58.581%. يليه معدل التغذية و نصف قطر الاداة على التوالي.

## 1. INTRODUCTION

Copper is considered difficult materials to machine. Copper-based alloys are used in the mass production of electrical components and water pipe fittings (John Kechagias et al 2009). The objective of machining is to produce high quality product with minimum cost. The control the cutting parameters is very important goal to achieve this objective (Ashok K.S. and Bidyadhar S., 2011).

Surface roughness plays an important role in evaluating and common measurement for identify the quality of machined products. There are many factors that affect surface roughness of any machined parts (Suleiman A. et al, 2011, Kompan C. and Somkiat J., 2010 and S. Thamizhmanii et al, 2007). These factors among others include: machining parameters, tool geometry, workpiece material, nature of chip produced, machine rigidity and cutting fluids used (Suleiman A. et al, 2011). The machining parameters spindle speed, feed rate, nose radius, and fixed depth of cut (0.1 mm) have considered in the current research when finishing turning operation was applied on pure copper. The determination of the optimal parameters is done by using taguchi method which is a statistical approach to overcome the limitation of the factorial and fractional factorial experiments by simplifying and standardizing the fractional factorial design (Nanaji Kshirsagar et al, 2012). It offers a simple and systematic approach to optimize design for performance, quality and cost. Signal to noise ratio and orthogonal array are two major tools used in Taguchi method. Taguchi method measures quality “the smaller is better” and “larger is better” (Akhar G. et al, 2008). These characteristics are given by the equations below (Mandal N. et al, 2011 and Durai M.B. et al, 2012).

**For the “smaller is better”, the equation is:**

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

For the “larger is better”, the equation is:

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

Where: S/N is the signal-noise ratio; n the number of observations; and  $y_i$  the observed data.

John Kechagias et al (2009) studied the effects of different process parameters: tool radius, feed rate, cutting speed, and cutting depth in turning of a copper alloy (GC-CuSn12) on the surface roughness. They had used Taguchi methodology in their work. Another work introduced by K.A. Mahajan et al (2010) deal with Oxygen Free High Conductivity Copper (OFHC) to a very high level of accuracy. They had tried to investigate effect of various cutting parameters as spindle speed, feed, depth of cut and tool nose radius on the surface finish by using Taguchi method.

H.M. Somashekara (2012) used cutting speed, feed rate, and depth of cut to obtain an optimal setting which results in an optimal value of surface roughness during machining Al 6351 – T6 alloy.

Krishankant et al (2012) introduce an optimization of turning process by effect of machining parameters applying Taguchi method. There are three machining parameters i.e. spindle speed, Feed rate, Depth of cut. Taguchi orthogonal array  $L_9$  is designed with three levels. Experiments are performed and material removal rate (MRR) is calculated. The metal removal rate was considered as the quality characteristic with the concept of “the larger-the-better”.

E. Daniel Kirby et al (2006) present an application of the Taguchi parameter design method to optimize the surface finish in a turning operation. The control parameters for this operation included: spindle speed, feed rate, depth of cut, and tool nose radius.

Ahmet Haşçalık and Ulaş Çaydaş (2008) studied the effect and optimization of machining parameters on surface roughness and tool life in a turning operation was investigated by using the Taguchi method. The experimental studies were conducted under varying cutting speeds, feed rates, and depths of cut.

## 2. EXPERIMENTAL WORK AND RESULTS

The traditional experimental design methods are too complex and difficult to use. The Taguchi method is an experimental design technique, which is useful in reducing the number of experiments by using orthogonal arrays (Ilhan Asilturk and Harun Akkus, 2011). In this research the orthogonal array used is  $L_9$  with nine experiments. This type of array look likes as in **Table 1**.

The workpiece material used in this study is pure copper that has the chemical composition shown in **Table 2**. The chemical composition has taken from Specialized Institute for Engineering Industries. The copper workpiece taken here had been portioned into 3 pieces; each one has 30 mm as a diameter and 60 mm as a length. The finishing turning operation is used to machine the material; therefore, the depth of cut is taken one value for all the nine experiments while the variables spindle speed, feed rate, and nose radius are taken into consideration as independent variables affecting the process. Three different values have been specified for each parameter. These levels are shown in **Table 3**. The cutting tool used here in this study was HSS. The cutting part of this tool has been rounded in shape by means of the manual grinding machine. The rounded curves have been checked by curvature measuring instrument.

Nine experiments were conducted on traditional machine named (STANKOLMPORT MOSCOW-USSR). After each individual experiment is performed, the setting of the machine is changed according to the combination of levels of the cutting parameters in orthogonal array for achieving the next experiment, and so on. For each experiment, three measures of roughness were taken, by using surface roughness tester Pocket Surf III shown in **Fig. 1**, and the arithmetic mean of them was computed. Also, the signal to noise ratio was calculated in terms of the characteristic quality “smaller is the better” which is described in eq. (1), and the values are placed in the last column of the **Table 4** that involves the experimental results.

## 3. MAIN EFFECT OF ROUGHNESS AND S/N RATIO

In order to find the optimum levels that are supposed they produce minimum surface roughness, the main effect is used. In main affect, for each level of the process parameter, the average of the response (surface roughness) and S/N ratio is determined corresponding to when the levels are labeled in the orthogonal array. The minimum value that the level has is the optimum level for that parameter. **Table 5** and **Table 6** show the results of the average of both surface roughness and S/N ratio and the rank of the parameters.

The effects of the cutting parameters plots in **Fig. 2** and **Fig. 3** illustrate the levels versus the surface roughness and the S/N ratio. It is seen that at level 3 of spindle speed there is minimum value of surface roughness, and this result is repeated at level 1 for both feed rate and nose radius; that is, at this level the minimum surface roughness value can be obtained.

## 4. ANALYSIS OF VARIANCE (ANOVA)

ANOVA is determined to identify the process parameters that are statistically significant. It is widely used in the design of experiment. The purpose of ANOVA analysis is to investigate which factors affect the quality characteristics significantly (Sang Heon Lim and

C. M. L., 2006). The analysis of variance table for the roughness test is shown in **Table 7**. The calculation of the total sum of squared deviations  $SS_T$  can be as follows (T.R. Lin, 2002).

$$SS_T = \sum_{i=1}^m \eta_i^2 - \frac{1}{m} \left[ \sum_{i=1}^m \eta_i \right]^2 \quad (3)$$

Where  $\eta_i$  represent the  $S/N$  ratio for each experiment;  $m$  represents the number of experiments in the orthogonal array;  $i = 1, 2, 3 \dots m$ .

The total sum of the squared deviations  $SS_T$  is the sum of the squared deviations parameters  $SS_p$  and the sum of the squared error  $SS_e$ . The  $SS_p$  can be formulated as (T.R. Lin, 2002);

$$SS_p = \sum_{j=1}^t \frac{(S\eta_j)^2}{t} - \frac{1}{m} \left[ \sum_{i=1}^m \eta_i \right]^2 \quad (4)$$

Where  $p$  is one of the parameters of the experiments

$j$  is the level number of the parameter  $p$ .

$t$  represents the reiteration of each level of the parameter  $p$

$S\eta_j$  represents the sum of the  $S/N$  ratio.

The sum of squares error can be calculated as (T.R. Lin, 2002);

$$SS_e = SS_T - SS_A - SS_B - SS_C \quad (5)$$

Where  $A$ ,  $B$ , and  $C$  represent three parameters that have been taken in this work spindle speed, feed rate, and tool nose radius respectively.

The equations for calculating of Degrees of freedom, Mean of square,  $F$  value, and contribution (%) are shown below (T.R. Lin, 2002):

$$\text{Degrees of freedom} = \text{Number of levels} - 1 \quad (6)$$

$$\text{Mean of square} = \frac{\text{Sum of square of parameter}}{\text{Degree of parameter's freedom}} \quad (7)$$

$$F \text{ value } (A, B, \text{ or } C) = \frac{\text{Mean square } (A, B, \text{ or } C)}{\text{Mean square of error}} \quad (8)$$

$$\text{Contribution } (\%) = \frac{\text{Sum of square of parameter } (A, B, C, \text{ or Error})}{\text{Total sum of squares}} \times 100 \quad (9)$$

## 5. CONFIRMATION TEST

It is an important step of the Taguchi method is the confirmation test which is used to check the predicted results and match them with the experimental values. After the optimum conditions of parameter levels are identified, the confirmation test is conducted. To confirm the results, 16 samples were machined under the optimum conditions that are: (1120 rpm) for spindle speed, (0.065 mm/rev) for feed rate, and (4 mm) for tool nose radius. All the experiments in this work were conducted by using 0.1 mm as a depth of cut. The results of confirmation test are depicted in **Table 8**. The mean of surface roughness as shown in the table of the confirmation test is (0.78  $\mu\text{m}$ ) which is very close to that determined in experiment such that the smallest value of surface roughness is (0.85  $\mu\text{m}$ ) as shown in **Table 4**.

## 6. CONCLUSIONS

The optimum conditions of finishing turning operation of pure copper had been studied using Taguchi method and ANOVA. According to the results, some points can be pointed. The combination of parameters levels ( $A_3B_1C_1$ ), that are spindle speed (1120 rpm), feed rate (0.065 mm/rev), and nose radius (4 mm), are recommended to get a good surface finish for finishing turning that workpiece material by using High Speed Steel tool HSS. From the percentage contribution in ANOVA table, the significant factor produced (58.581%), which is for spindle speed. That represent the highest percent contribution; therefore, it can be said that the spindle speed is a dominant factor in the process of machining pure copper. The feed rate and tool nose radius take the second and third rank respectively.

Table1: Taguchi  $L_9$  orthogonal array (Krishankant et al, 2012)

| Experiment number | Factors and Levels |   |   |
|-------------------|--------------------|---|---|
|                   | A                  | B | C |
| 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 2: Chemical composition of commercial pure copper

| Element | Wt%    |
|---------|--------|
| Zn%     | 0.006  |
| Pb%     | 0.0003 |
| Sn%     | 0.0006 |
| P%      | 0.0003 |
| Mn%     | 0.0004 |
| Fe%     | 0.043  |
| Ag%     | 0.0008 |
| Si%     | 0.027  |
| Cr%     | 0.001  |
| As%     | 0.0004 |
| Al%     | 0.0005 |
| S%      | 0.0009 |
| Bi%     | 0.0004 |
| Cu%     | 99.9   |

Table 3: Parameter's levels

| level | Process Parameters  | Levels |       |       |
|-------|---------------------|--------|-------|-------|
|       |                     | A      | B     | C     |
| 1     | Spindle Speed (rpm) | 710    | 900   | 1120  |
| 2     | Feed Rate (mm/rev)  | 0.065  | 0.114 | 0.160 |
| 3     | Tool Radius (mm)    | 4      | 6     | 8     |

Table 4: Cutting conditions, Surface Roughness S.R, and S/N ratio results

| Exp.<br>Run | Experimental conditions |                        |                      | Designation                                  | Individual S.R<br>measurements for each<br>experiment |      |      | S.R<br>average<br>(R <sub>a</sub> ) μm | S/N<br>(dB) |
|-------------|-------------------------|------------------------|----------------------|----------------------------------------------|-------------------------------------------------------|------|------|----------------------------------------|-------------|
|             | A                       | B                      | C                    |                                              | n1                                                    | n2   | n3   |                                        |             |
|             | Spindle<br>Speed<br>rpm | Feed<br>Rate<br>mm/rev | Tool<br>Radius<br>mm |                                              | μm                                                    | μm   | μm   |                                        |             |
| 1           | 710                     | 0.065                  | 4                    | A <sub>1</sub> B <sub>1</sub> C <sub>1</sub> | 1.25                                                  | 1.34 | 1.06 | 1.217                                  | -1.743      |
| 2           | 710                     | 0.114                  | 6                    | A <sub>1</sub> B <sub>2</sub> C <sub>2</sub> | 1.90                                                  | 2.06 | 1.60 | 1.853                                  | -5.405      |
| 3           | 710                     | 0.160                  | 8                    | A <sub>1</sub> B <sub>3</sub> C <sub>3</sub> | 1.96                                                  | 2.11 | 1.64 | 1.903                                  | -5.636      |
| 4           | 900                     | 0.065                  | 6                    | A <sub>2</sub> B <sub>1</sub> C <sub>2</sub> | 1.12                                                  | 0.90 | 1.25 | 1.090                                  | -0.824      |
| 5           | 900                     | 0.114                  | 8                    | A <sub>2</sub> B <sub>2</sub> C <sub>3</sub> | 0.99                                                  | 1.64 | 1.19 | 1.273                                  | -2.292      |
| 6           | 900                     | 0.160                  | 4                    | A <sub>2</sub> B <sub>3</sub> C <sub>1</sub> | 0.97                                                  | 1.09 | 1.33 | 1.130                                  | -1.137      |
| 7           | 1120                    | 0.065                  | 8                    | A <sub>3</sub> B <sub>1</sub> C <sub>3</sub> | 1.23                                                  | 1.03 | 0.89 | 1.050                                  | -0.500      |
| 8           | 1120                    | 0.114                  | 4                    | A <sub>3</sub> B <sub>2</sub> C <sub>1</sub> | 0.99                                                  | 0.85 | 1.22 | 1.020                                  | -0.268      |
| 9           | 1120                    | 0.160                  | 6                    | A <sub>3</sub> B <sub>3</sub> C <sub>2</sub> | 1.30                                                  | 1.43 | 1.17 | 1.300                                  | -2.308      |

Table 5: Main effect and average results for R<sub>a</sub> (Average surface Roughness)

| Symbol | Cutting Parameters | Average of S.R (R <sub>a</sub> ) μm |        |        | Max-Min<br>μm | Rank |
|--------|--------------------|-------------------------------------|--------|--------|---------------|------|
|        |                    | Level1                              | Level2 | Level3 |               |      |
| A      | Spindle Speed      | 1.658                               | 1.164  | 1.123* | 0.535         | 1    |
| B      | Feed Rate          | 1.119*                              | 1.382  | 1.444  | 0.325         | 2    |
| C      | Tool Radius        | 1.122*                              | 1.414  | 1.409  | 0.292         | 3    |

\*Optimum Level

Table 6: Main effect and average results for S/N ratio (Signal to noise ratio)

| Symbol | Cutting Parameters | Average of S/N dB |        |         | Max-Min<br>dB | Rank |
|--------|--------------------|-------------------|--------|---------|---------------|------|
|        |                    | Level1            | Level2 | Level3  |               |      |
| A      | Spindle Speed      | -4.261            | -1.418 | -1.025* | 3.236         | 1    |
| B      | Feed Rate          | -1.022*           | -2.655 | -3.027  | 2.005         | 2    |
| C      | Tool Radius        | -1.049*           | -2.846 | -2.809  | 1.797         | 3    |

\*Optimum Level

Table 7: ANOVA output for the surface roughness

| Symbol | Sum of Squares | Degrees of Freedom | Mean Squares | F value | Contribution (%) |
|--------|----------------|--------------------|--------------|---------|------------------|
| A      | 18.712         | 2                  | 9.356        | 225.446 | 58.581           |
| B      | 6.822          | 2                  | 3.411        | 82.193  | 21.357           |
| C      | 6.325          | 2                  | 3.1625       | 76.205  | 19.802           |
| Error  | 0.083          | 2                  | 0.0415       |         | 0.26             |
| Total  | 31.942         | 8                  |              |         | 100              |

Table 8: Confirmation test output

| Specimen no. | R <sub>a</sub> (μm) |
|--------------|---------------------|
| 1            | 0.72                |
| 2            | 0.55                |
| 3            | 0.90                |
| 4            | 0.63                |
| 5            | 0.81                |
| 6            | 0.65                |
| 7            | 0.77                |
| 8            | 1.13                |
| 9            | 0.61                |
| 10           | 0.93                |
| 11           | 0.73                |
| 12           | 0.91                |
| 13           | 0.57                |
| 14           | 0.84                |
| 15           | 0.69                |
| 16           | 1.05                |
| Mean         | <b>0.78</b>         |



Fig. 1: Surface Roughness Equipment.

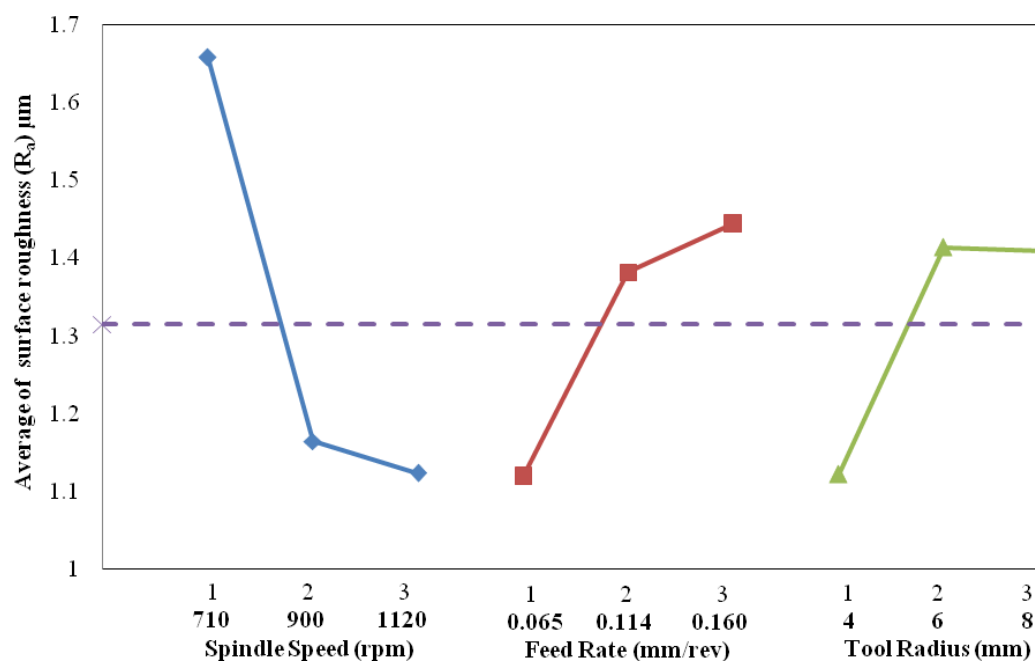


Fig. 2: Main effects plot for  $R_a$  with parameter levels

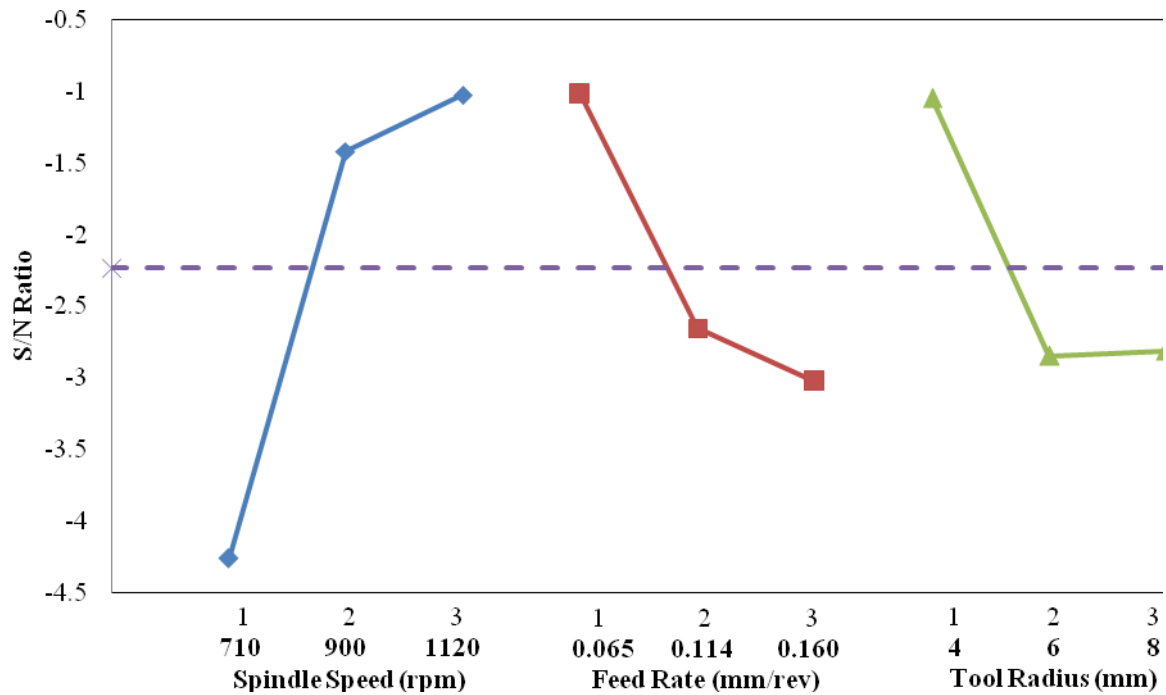


Fig. 3: Main effects plot for S/N with parameters levels

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