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# A PARAMETER DESIGN IN TURNING OF COPPER ALLOY

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**Abstract.** An optimization of the cutting parameters during turning of a copper alloy (GC-CuSn12) using the Taguchi design is attempted. Test specimens in the form of near-to-net-shape bars and a titanium nitride coated cemented carbide (T30) cutting tool were used. The independent variables considered were the cutting speed, feed rate, cutting depth and tool nose radius. An orthogonal matrix experiment ($L_9(3^4)$) was conducted and the arithmetic mean roughness was measured and optimised according to the process parameters using an analysis of means and an analysis of variances. Finally, an additive model was applied on the experimental results and a verification experiment, using the best combination of parameters, was carried out in order to compare the actual and the predicted values.

**Keywords:** turning, surface roughness, optimization, modelling

## 1. Introduction

Copper-based alloys are used in the mass production of electrical components and water pipe fittings. They are usually machined using high speed CNC machines, which are mostly very high speed lathes fed with brass wire of a relatively small diameter, so that the maximum speed is limited to 140-220m/min, although the tooling is capable of a good performance at much higher speeds.

When copper alloys are machined, very high forces act on the tool, particularly at low cutting speeds. This is due to the large contact area on the rake face resulting in a small shear plane angle and thick chips [1].

This is the main reason why copper is considered one of the most difficult materials to machine. Generally, when the cutting speed is increased the cutting forces are decreased and the surface finish is improved.

A study of the effects of different process parameters: tool radius (r), feed rate (f), cutting speed (V), and cutting depth (a) in turning of a copper alloy (GC-CuSn12), on the average mean surface roughness ($R_a$), is attempted in the current work, using the Taguchi methodology.

Thus, an $L_9(3^4)$ orthogonal matrix experiment was conducted [2]. A matrix experiment consists of a set of experiments where the settings of several process parameters to be studied are changed from one experiment to another in a combinatory way.

Experimental results are used in order to estimate the process parameter effects on the surface roughness by an analysis of means (ANOM) and an analysis of variances (ANOVA) approach.

The best combination of process parameter levels is suggested by the ANOM approach and its performance is predicted using the corresponding additive model proposed by the methodology.

Finally, a verification experiment was conducted to evaluate the methodology.

## 2. Experimental setup

The material used for cutting is specified as GC-CuSn12. It is a copper alloy containing 84 to 85% Cu, 11 to 14% Zn, under 1% Pb, less than 2% Ni, and finally under 0.2% Sb.

The machine used for the experiments was a Cortini F100 CNC machine lathe (3.7kW) equipped with a GE Fanuc Series O-T control unit. The test specimens were in the form of bars, 32mm in diameter and 80mm in length for near–to- net –shape machining. Tailstock was not used (figure 1).

The cutting tools were titanium nitride screw-on positive inserts, CCMT 09T30, with a 0.4 and 0.8mm tool nose radii, accordingly (figure 2).

Figure 1. Cortini F100 CNC machine lathe

Figure 2. Machined specimens and inserts

The average surface roughness ($R_a$, μm) was measured using the Taylor Hobson, Talysurf 10 tester (figure 3).

Average roughness ($R_a$) can be obtained by taking the average of 1150 different positional deviations over a 4 mm length with a cut-off at 0.8mm. The equation of average surface roughness is given as

$$R_a = \frac{1}{1150}\sum_{1=1}^{1150}|z_i| \quad (1)$$

where $z_i$ is the value of surface roughness in irregular measurement points.

Figure 3. Surface roughness measurements.

A four parameter design was performed as shown in Table 1. Note that Level 1 and level 3 for the parameter r assign the same value. This is not an obstacle for the methodology followed.

Table 1. Parameter Design

| | | levels | | |
|---|---|---|---|---|
| No | Process Parameters | 1 | 2 | 3 |
| 1 | Tool Radius (r) (mm) | 0.4 | 0.8 | 0.4 |
| 2 | Feed Rate (f) (mm/rev) | 0.05 | 0.15 | 0.25 |
| 3 | Cutting Speed (V) (m/min) | 100 | 150 | 200 |
| 4 | Cutting Depth (a) (mm) | 0.2 | 0.6 | 1 |

The standard ($L_9(3^4)$) orthogonal matrix experiment was used (Table 2).

Table 2. Orthogonal Array $L_9(3^4)$

| | Column | | | |
|---|---|---|---|---|
| No Exp | 1 | 2 | 3 | 4 |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

Columns 1, 2, 3, and 4 are assigned to tool radius (r), feed rate (f), cutting speed (V) and depth of cut (a), respectively.

## 3. Experimental results

The Taguchi design method is a simple and robust technique for optimizing the process parameters. In this method, main parameters, which are assumed to have an influence on process results, are located at different rows in a designed orthogonal array. With such an arrangement, randomized experiments can be conducted. In general, signal to noise (S/N) ratio (n, dB) represents quality characteristics for the observed data in the Taguchi design of experiments.

In the case of surface roughness amplitude [3-9], lower values are desirable. These S/N ratios in the Taguchi method are called as the smaller-the-better characteristics and are defined as follows:

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

where $y_i$ is the observed data at the $i_{th}$ trial and $n$ is the number of trials. From the S/N ratio, the effective parameters having an influence on process results can be obtained and the optimal sets of process parameters can be determined.

Based on Robust design, the standard orthogonal array ($L_9(3^4)$) has been selected in order to perform the matrix experiment (Table 3). Three levels for each factor were selected (Table 1). Following the ($L_9(3^4)$) orthogonal array nine experiments were performed with each experiment producing a test part which was tested for average surface roughness (Ra, μm). Each performance measurement $\eta_i$ is then calculated according to the following formula:

$$\eta_i = -10\log_{10}(Ra_i) \qquad (3)$$

Table 3. Matrix Experiment

| Ex. No. | r | f | V | a | $R_a$ (μm) | η |
|---|---|---|---|---|---|---|
| 1 | 0.4 | 0.05 | 100 | 0.2 | 0.24 | 6.198 |
| 2 | 0.4 | 0.15 | 150 | 0.6 | 1.51 | -1.790 |
| 3 | 0.4 | 0.25 | 200 | 1 | 0.54 | 2.676 |
| 4 | 0.8 | 0.05 | 150 | 1 | 0.44 | 3.565 |
| 5 | 0.8 | 0.15 | 200 | 0.2 | 0.27 | 5.686 |
| 6 | 0.8 | 0.25 | 100 | 0.6 | 0.69 | 1.612 |
| 7 | 0.4 | 0.05 | 200 | 0.6 | 0.34 | 4.685 |
| 8 | 0.4 | 0.15 | 100 | 1 | 0.84 | 0.757 |
| 9 | 0.4 | 0.25 | 150 | 0.2 | 0.32 | 4.949 |
| Mean (m) | | | | | 0.577 | 3.149 |

For each process parameter r, f, V and a, an average $m_i$ for every value (level) was calculated (Table 4).

Table 4: Mean parameter values

| Mean parameter value | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| $m_{ri}$ | 2.361 | 3.621 | - |
| $m_{fj}$ | 4.816 | 1.551 | 3.079 |
| $m_{Vk}$ | 2.856 | 2.241 | 4.349 |
| $m_{al}$ | 5.611 | 1.502 | 2.333 |

Based on the average values, an analysis of means (ANOM) diagram (Figure 4) is constructed indicating the impact of each factor level on the performance $\eta$ of the parts produced. Thus, based on the ANOM, one can derive the optimum combination of process variables, with respect to performance. The optimum level for a factor is the level that gives the maximum value of $\eta$ in the experimental region.

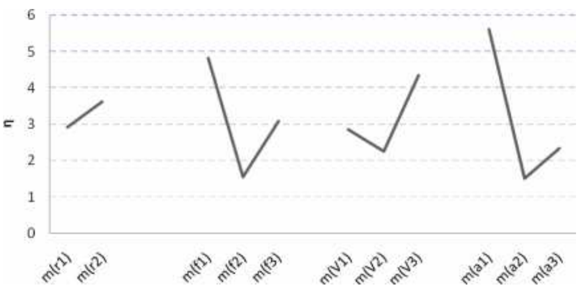


Figure 4. ANOM diagram

According to the ANOM diagram, the feed rate and the cutting depth are the main contributors to the performance. The combination of the levels that maximizes the performance is: r=0.8mm, f=0.05mm/rev, V=200m/min, and a=0.2mm.

Robust design performs an analysis of variables (ANOVA) of the experimental results in order to evaluate the relative importance of the process parameters and the error variances. The ANOVA analysis results can be seen in Table 5.

Table 5. ANOVA analysis

| | DoF | SoS | MS | F | % |
|---|---|---|---|---|---|
| r | 1 | 0.837 | 0.837 | 0.421 | 1.5% |
| f | 2 | 16.012 | 8.006 | 4.023 | 29.5% |
| V | 2 | 7.051 | 3.526 | 1.772 | 13.0% |
| a | 2 | 28.316 | 14.158 | 7.115 | 52.2% |
| | | | | | |
| Total | 8 | 54.205 | | | |
| Error (e) | 1 | 1.990 | 1.990 | | |

DoF: Degrees of Freedom
SoS: Sum of Squares
MS: Mean Squares

Figure 5 shows the influence of each factor on the performance of the turning process. According to the ANOVA analysis, the depth of cut influences the performance by 52.2%, the feed rate by 29.5%, the cutting speed 13% and tool radius by 1.5%.

The variance of the effect of each factor level for this case is [2]:

$$\frac{1}{3}\sigma_e = \frac{1}{3}(1.99) = 0.663 \qquad (4)$$

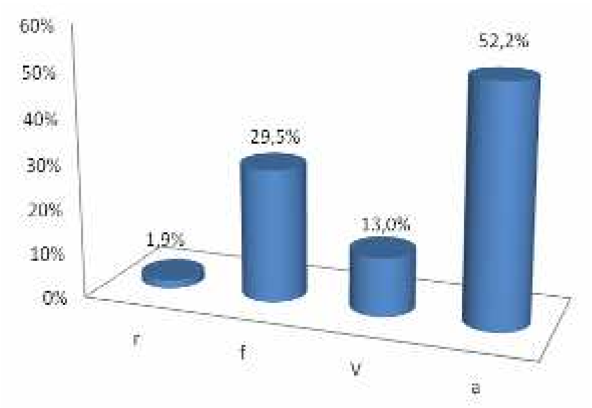


Figure 5. Factors percentage influence

thus, the width of the two standard deviation confidence interval, which is approximately 95 percent confidence interval for each estimated effect, is:

$$e = \pm 2\sqrt{0.663} = \pm 0.163 \quad (5)$$

In order to establish a relationship between the $\eta$ performance and the process parameters, one can derive the additive model of the form:

$$\eta = m + (m_{ri} - m) + (m_{fj} - m) + (m_{Vk} - m) + (m_{al} - m) \pm e \quad (6)$$

where: $\eta$ is the performance measure, m is the overall mean of all the performance measures (Table 3), and $m_{ri}$, $m_{fj}$, $m_{Vk}$, and $m_{al}$ are the means of each parameter level (Table 4).

For example the prediction of the performance of the best combination (r=0.8mm, f=0.05mm/rev,V=200m/min, and a=0.2mm) is:

$$\eta_{2131} = m + (m_{r2} - m) + (m_{f1} - m) + (m_{V3} - m) + (m_{a1} - m) \pm e \quad (7)$$

or

$$\eta_{2131} = 3.149 + (3.621 - 3.149) + (4.816 - 3.149) + (4.349 - 3.149) + (5.611 - 3.149) \pm 0.163 \quad (8)$$

or

$$\eta_{2131} = 8.951 \pm 0.163 \quad (9)$$

which means an average surface roughness $R_a$=0.127μm with the two standard deviation confidence intervals to be [0.087496, 0.185248] μm.

An evaluation experiment was performed and the $R_a$ was found to be 0.17μm; a value which is acceptable as it is within the above confidence intervals.

## 4. Conclusions

The surface roughness of copper alloy near-to-net-shape parts during turning was measured according to a matrix experiment. The optimal process parameters values for the experimental region are: Tool radius, r=0.8mm; Feed rate, f=0.05mm/rev; Cutting speed, V=200m/min; and Cutting depth, a=0.2mm.

According to the experimental results: (i) the surface roughness was influenced mostly by the depth of cut (by 52.2%) and by the feed rate (by 29%), (ii) the cutting speed affects the performance by 13%, and finally, (iii) the tool radius affects the performance the least (by about 1.5%).

The results show that in turning of copper alloys the most important parameters are the depth of cut and the feed rate. The surface finish is improved when the cutting speed is increased but the influence of the latter is less than the above two parameters.

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