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EXPERIMENTAL INVESTIGATION AND REGERSSION MODELLING OF SURFACE ROUGHNESS OF COPPER DURING CNC TURNING

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ABSTRACT:

In today's competitive and dynamic market environment, the main confront of metal-based industry is to maintain higher productivity and the surface excellence of the machined parts. In utmost situation, performance of turning process is measured in terms of quality of surface generated. Fatigue strength, corrosion resistance and creep life increases as superiority of turned surface improves significantly. Therefore ideal surface finish is usually required and appropriate parameters need to be selected to achieve required quality of surface. The present research intends to apply use of Taguchi method to carry out performance analysis of the CNC turned parts to achieve high surface finish on copper alloy material. This paper explores the corollary of process parameters in turning of copper alloy on HAAS CNC lathe machine. In this research work, Taguchi's L_9 orthogonal array is used to carry out CNC turning operation on copper alloy. To study the performance characteristics in CNC turning signal to noise ratio is evaluated. The output response like surface roughness is analyzed considering effects of factors like spindle speed, tool feed rate and uncut depth of work piece or depth of cut for tool. For predicting the surface roughness, regression mathematical model (in terms of linear and quadratic terms) has also developed from the experimental result, which will be useful to envisage surface roughness value on different combination of selected parameters. From verification experiments it is observed that, calculated surface roughness from model equation varies in the range of 0 to 10% with respect to an experimental value. Thus, it is possible to obtain effective machine utilization and present work will be quite useful for manufacturing engineers working in the field of CNC Machining.

KEYWORDS: Surface Roughness; CNC; Copper alloy; Regression models.

1.0 INTRODUCTION:

Turning is the most extensively used among all the cutting processes. In the present manufacturing era, significance & scope of CNC turning operations greatly increased. Due to budding competition the efforts are intended for the economical production of machined component with high surface finish. Hence surface roughness is one of the most important quality measures in mechanical products [1].To maintain higher quality functional feature in higher precision components, surface roughness becomes key factor in the modern manufacturing process. Physical & mechanical properties like corrosion resistance, creep life and fatigue strength are considerably enhanced as surface finish progressively improves in the turning performance. Functional characteristic of component like surface wear resistance, friction, reflection of light from exterior and heat transmission are dependant of surface roughness. The properties like load bearing capability, wettability of lubricant and fatigue resistance are also varying with degree of surface finish. Consequently preferred surface finish is usually required and appropriate parameters need to be selected to achieve required quality of surface.

2.0 LITERATURE REVIEW OF PRESENT RESEARCH WORK

Material removal rate (MRR) is affected by depth of cut followed by the nose radius during turning of aluminium alloy 6061 by carbide inserts. [2] .Optimum turning conditions for the power factor and energy efficiency are same and occur at 248.69 m/min. cutting speed, 0.3 mm/rev. feed rate, 1.8 mm depth of cut and 0.8 mm nose radius when CNC rough turning is carried out for EN 353 alloy steel with multi-layer coated tungsten carbide.[3] .An optimization study by machining a hardened AISI 4140 grade (63 HRC) steel on a lathe by using Al2O3 + TiCN coated ceramic inserts showed that cutting speed is the only the significant factor influencing the tool wear [4].The 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 found the most favorable cutting parameters when multiple output optimization for high speed during CNC turning of AISI P-20 tool steel. [5].

The cutting performance on Ti-6Al-4V alloy with synthetic oil is found to be better when compared to dry and servo cut oil and water in reducing surface roughness [6]. Performance of neural network model trained with particle swarm optimization model is superior in terms of computational speed and accuracy [7]. Nose radius and cutting environment found to be the most significant factors for both surface roughness and MRR during turning experiment on EN 24 alloy steel using TiN coated tungsten carbide inserts [8]. The feed rate was the dominant factor affecting surface roughness, which is minimized when the feed rate and depth of cut were set to the lowest level, while the cutting speed is set to the highest level when the AISI 304 austenitic stainless work piece was machined by a coated carbide insert under dry conditions [9].

Taguchi Approach of optimization is also carried out in CNC Turning. The machining was done with cermet inserts. It was observed that the cutting velocity is the key factor to reduce dimensional tolerances followed by feed rate and depth of cut when optimization is carried out using taguchi approach during CNC Turning [10].

To achieve the desired surface finish, a good predictive model is required for stable machining. To the best of the author's knowledge, very few efforts have been made to develop mathematical modeling during CNC turning operation.

Generally, it is found that regression models developed so far have a complex relationship between output response like surface roughness and controlling parameters, work materials. The present study proposes application of Taguchi method to achieve higher surface finish. The objective of this experimental investigation is to explore process parameters for a turning of Copper alloy on CNC turning machine set up.

The simplified regression mathematical model has also developed from the experimental result, fundamentals of Taguchi's approach and MATLAB which will be useful for predicting the Surface Finish on different selected parameters.

3.0 EXPERIMENTATION:

3.1 EXPERIMENTAL SETUP AND MATERIAL USED:

The experiments were conducted on HAAS CNC turning machine, which is highly versatile and up to date with the latest CNC technology, driven by latest CNC control system. HAAS Concept Turn 250 has a TCM 'C Axis' option with 6 driven tools – power 1.2 kw, 200 – 6000 rpm. The experiments were conducted on standardized machine set up as shown figure 1. Max turning diameter: 85 mm, Distance between centre 405 mm, Travel X Z: 100*250 mm, Spindle speed: 60 – 6300 rpm, Max bar stock diameter: 25.5 mm, Feed force: 0-3 N and Display: 12" LCD.

Figure 1:- HAAS CNC

The work-piece used in the present work is copper Alloy in as cast condition having diameter 17 mm and length 80 mm (20mm length used for each experiment). The detail composition of material is as shown in the Table 3. The cutting tool used is silicon carbide insert. The coolant used is Kerosene.

Table 3: Chemical Composition

Sr.No.	Chemical Element	% Percent
1	Iron (Fe)	0.1
2	Silicon (Si)	0.1
3	Chromium (Cr)	0.6-1.2
4	Lead (Pb)	0.05
5	Copper	Remaining

3.2. PLANNING FOR EXPERIMENTATION:

The experiments were conducted on HAAS CNC turning machine set up with developed CNC programme with Fanuc Control. Based on literature review and preliminary investigation three parameters namely spindle speed, tool feed and depth of cut were found to be an important parameters during the CNC machining process. A preliminary design of experiments using the L9 (33) orthogonal array (OA) was carried out in order to assess the relative effect of these three machining parameters. Three levels of each factor were used in the experimental design through an L9 orthogonal array [11]. The actual values of three parameters at different three levels are listed in the Table 1.

Table 1: Parameters and their levels

Machining Parameters	**Level 1**	**Level 2**	**Level 3**
Spindle Speed (*N*), rev/min **(A)**	600	1200	1800
Tool Feed (*f*), *mm/min*,**(B)**	0.08	0.14	0.2
Depth of Cut (*D*), *mm*,**(C)**	0.4	0.8	1.2

The experiments were carried out to analyze the influence of three process parameters i.e. spindle speed, tool feed and depth of cut during the CNC operation on Surface Roughness (SR). Parametric combinations for nine experiments with coded and actual values are summarized in Table 2.

Table 2: Combination of control parameters based on L_9 array

Expt. No.	Levels of parameters			Actual values of parameters		
	N (A)	*f* (B)	D (C)	N *rev/min*	*f* *mm/min*	*D* *mm*
1	1	1	1	600	0.08	0.4
2	1	2	2	600	0.14	0.8
3	1	3	3	600	0.2	1.2
4	2	1	2	1200	0.08	0.8
5	2	2	3	1200	0.14	1.2
6	2	3	1	1200	0.2	0.4
7	3	1	3	1800	0.08	1.2
8	3	2	1	1800	0.14	0.4
9	3	3	2	1800	0.2	0.8

Some of sample developed CNC programme are shown below

```
Experiment:1
001432;
;
(88456);
G28;
T101;
G97 S600 M03;
M09;
G00 X17.00;
G00 Z0;
G01 X16.6 F0.08
G01 Z-20.F0.08;
G00 X17.00;
G00 Z0;
G28;
M30;
```

```
Experiment:2
001432;
;
(88456);
G28;
T101;
G97 S600 M03;
M09;
G00 X17.00;
G00 Z0;
G01 X16.2 F0.2;
G01 Z-20.F0.2;
G00 X17.00;
G00 Z0;
G28;
M30;
;
```

```
Experiment:3
001432;
;
(88456);
G28;
T101;
G97 S600 M03;
M09;
G00 X17.00;
G00 Z0;
G01 X14.6 F1.2;
G01 Z-20.F1.2;
G00 X17.00;
G00 Z0;
G28;
M30;
;
```

3.3 MEASUREMENT SCHEME OF RESPONSES:

In the present experimentation, the machining of performance was measured in terms of surface roughness parameters, i.e., (Ra). The experimental observations were transformed into a signal to noise (S/N) ratio. Surface roughness was measured using surface roughness tester handy- SURF 10, (Metrix) as shown in the figure 2 & 3.

Figure 2: Surface Tester (Front View)

Figure 3: Surface Tester *handv SURF* 10 Stvlus

4.0 EXPERIMENTAL RESULTS OF SURFACE: ROUGHNESS OF COPPER:

The Experimental values of surface Roughness (R*a*) and calculated S/N ratio of SR calculated using Equation as shown in the Table 3.

Table 3: Experimental results and S/N ratio of SR

Experiment No.	Surface Roughness Rate in µms	S/N Value On Surface Roughness (dB)
1	0.0100	40.0000
2	0.1650	15.6503
3	0.2460	12.1813
4	0.0610	24.2934
5	0.0805	21.8841
6	0.1490	16.5363
7	0.0560	25.0362
8	0.0670	23.4785
9	0.4530	6.8780

Average S/N ratio (η) for SR= 20.660 dB

Different Mean graph and S/N ratio graphs have been plotted to show the effects of three controlling factors namely spindle speed, tool feed and depth of cut on machining characteristics like Surface Roughness. The analysis is made using MINITAB-15 software. These mean graph and S/N ratio graphs are shown in the figure 2.2 & 2.3 below.

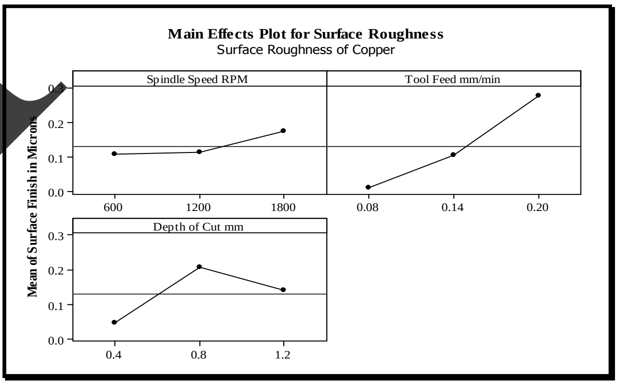

Figure 2.2:-Main Effects of Average SR with variation of input parameters.

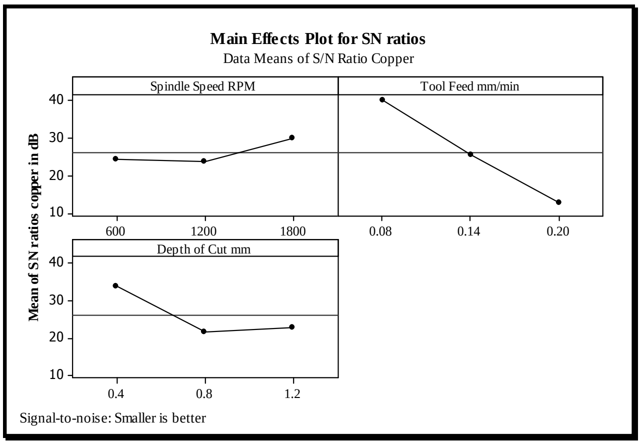

Figure 2.3: S/N ratio curves of process parameters for SR

5.0 ANALYSIS BASED ON SIGNAL-TO-NOISE (S/N) RATIO CURVES:

5.1. PARAMETRIC INFLUENCE ON SURFACE ROUGHNESS (SR):

According to Taguchi-based methodology, as mentioned earlier, for the Surface Roughness (SR) lower-the better condition is considered.

The obtained experimental results and S/N ratio which are calculated from the equation for each machining response at different experimental combinations of machining parameters according to L 9 orthogonal array. Different S/N ratio graphs have been plotted to show the effects of three controlling factors namely spindle speed; tool feed rate and depth of cut on machining characteristics i.e. SR. The present work investigates the effect of operating parameters such as cutting speed, feed rate and depth of cut on SR.

Figure 2.2 shows the main effect graph of SR obtained while machining of copper sample work pieces. It is seen from these figures that the surface roughness enhances with increase in the cutting speed (spindle speed). Between level 1 and level 3, the cutting speed increases from 600 rpm to 1800 rpm and SR increases from 0.1 μm to 0.2 μm.At higher cutting speeds SR increases due to factors such as machine vibration, indirectness in work piece, wear of tool and machining part temperature.

The study reveals that the roughness of machined surface is directly affected by the spindle speed along with rate of tool feed. It also shows increment in the surface roughness at upper rate of tool feed and is higher at lower cutting speeds and vice versa for overall range feed rates. It is also observed from experimental result that the surface roughness stridently raised due to added tool feed rate from 0.08 to 0.2 mm/sec. Higher heat generation and thus wear of tool caused due to additional feed rate leads to higher surface roughness. The highest feed rate also results in elevated chatter owing to higher cutting forces and produced incomplete machining at faster travel of cutting tool causes a higher surface roughness.

It is also revealed that SR increases with depth of cut of tool. This is due to rapid plastic deformation of work piece under high cutting forces which may create vibration and increases temperature of work piece and tool wear.

5.0. DEVELOPMENT OF MATHEMATICAL MODEL:

5.1 MATHEMATICAL MODELS OF SURFACE ROUGHNESS FOR COPPER:

Mathematical models to represent the relationship among Surface Roughness (SR) and various controllable machining parameters of CNC machining of Copper alloy have developed by regression analysis on the basis of L_9 orthogonal array of robust design. Since Spindle Speed (N), Tool Feed (*f*) and Depth of cut (D) have most significant influence on SR; the response equation has been developed considering only linear and quadratic effects of Spindle Speed, Tool Feed and Depth of cut. The appropriate equation in the form of linear & square term has been decided and coefficients have been determined using MATLAB software. The developed mathematical model for SR for Copper is follows:

$$Y_{SR} = -0.446884-0.00013364\ X_1--0.6841\ X_2+1.25524\ X_3+7.86*10^{-8}X1^2+10.36\ X2^2-0.71062\ X3^2$$

Where X_1=Spindle Speed,
X_2=Tool Feed and
X_3= Depth of Cut

The verification experiments are carried out to check the accuracy of developed mathematical model. The Values of verification experimental results are shown in the Table 5.

Table 5 Verification Experiments for model of Surface Roughness in μm

Verification Expt No.	Spindle Speed	Tool Feed mm/sec	Depth of Cut (mm)	Model value Y_{SR} (μms)	Average Experimental value S_R (μms)	Difference	Variation in %
1	1500	0.12	1	0.141	0.152	-0.011	-7.80
2	1000	0.15	0.6	0.126	0.137	-0.011	-8.73
3	1600	0.18	0.5	0.203	0.223	-0.020	-9.85

From verification experiments it is found that, an experimental value of SR and model values varies in the range of 0 to 10%.

6.0 CONCLUSIONS:

The present study consists development of CNC programming, CNC machining using Taguchi approach and development of mathematical modeling based on the analysis of the acquired test results to study the influence of various turning process parameters on response criteria i.e. Surface Roughness (SR).

However within the limitation of time and resources, the following conclusions may be drawn:

(i). The present work investigates the effect of operating parameters such as cutting speed, feed rate and depth of cut on SR. It is observed while machining of Copper, surface roughness enhances with increase in the cutting speed when the cutting speed increases from 600 rpm to 1800 rpm and SR increases from 0.1 μm to 0.2 μm. (ii) At higher cutting speeds SR increases due to factors such as machine vibration, indirectness in work piece, wear of tool and machining part temperature.

(ii). It also shows increment in the surface roughness at upper rate of tool feed and is higher at lower cutting speeds and vice versa for overall range feed rates. Further, It is also observed that the surface roughness sharply increases due increase in feed rate from 0.08 to 0.2 mm/sec.

(iii). Further, observed that the surface roughness stridently raised due to added tool feed rate from 0.08 to 0.2 mm/sec. Higher heat generation and thus wear of tool caused due to additional feed rate leads to higher surface roughness. The highest feed rate also results in elevated chatter and produced incomplete machining at faster travel of cutting tool causes a higher surface roughness.

(iv). It is also revealed that SR increases with depth of cut of tool. This is due to rapid plastic deformation of work piece under high cutting forces which may create vibration and increases temperature of work piece and tool wear.

(v). Regression mathematical models have also been developed for SR for Copper work material. It is also proved that developed models are adequate to judge of output responses at any input parameters within the range. From verification experiments it is found that that, an experimental value of SR and model values varies in the range of 0 to10 %.

Various stages of experimentation and analysis, experimentation based on Taguchi method through the present work will be quite useful for manufacturing engineers working in the area of CNC Machining of copper alloys.

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