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Study on Spindle Vibration and Surface Finish in Turning of Al 7075

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Abstract. In this study, the relationship between the spindle vibration and surface roughness was investigated and the effect of the cutting parameters on surface roughness and spindle vibration during the machining of Aluminum alloy 7075 (Al 7075) were determined. Experimental studies have been carried out on a CNC turning machine using coated cemented carbide cutting tools under dry cutting environment. L_{64} full factorial design of experiments was used to investigate the optimal machining parameters for spindle vibration and surface roughness. The influences of machining parameters on vibration and surface roughness were evaluated by using analysis of variance (ANOVA) and main effect plots. The results revealed that the feed rate was the most effective cutting parameters on spindle vibration and surface roughness. The machine tool vibration amplitude and surface roughness values were significantly increased with increasing cutting feed. The depth of cut and cutting speed have the least effect on the spindle vibration and indicated an insignificant effect on surface roughness. Mathematical equations were developed to predict the vibration and surface roughness values using the regression analysis.

Introduction

The finished surface quality of the work part is one of the most significant requirements for the final product due to the dimensional accuracy, friction, corrosion resistance and fatique strength. The cutting feed, cutting speed and cutting insert radius are the known most effective factors for the surface quality. On the other hand, machine tool rigid, cutting environment with dry or wet, cutting parameters, chip formation and vibrations are also most important factors for the surface quality of finished part [1]. Therefore, numerous researchers investigated the surface roughness and developed predictive models for turning and milling operations [2- 5]. Machine tool rigid and spindle vibration are very important requirements for the product quality and cutting insert performance. Several researchers were examined the influence of the relationship between the vibration and surface quality. Abouelatta and Madl [6] generated an estimation equations based on the cutting variables and machine tool vibrations in turning experiments. A correlation between machining vibration and surface roughness in turning process was reported by the authors. Beauchamp et al. [7] investigated the vibration and surface finish under dry turning of mild carbon steel. They concluded that surface roughness values were improved at lower feed rate and higher cutting speed. They reported that the chip-thickness and amplitude of tool vibration at resonance were affected the tool's cutting behavior during machining process. Jang et al. [8] studied the relative machining vibrations between tool and workpiece and developed a real-time monitoring algorithm. The test results show that the vibration-free surface roughness values carry certain frequency components and machine-tool structure is closely related to the natural frequencies of a spindle-workpiece, especially at high frequencies. Mer and Diniz [9] machined AISI 4340 steel using coated carbide cutting tool and investigated the influence of the vibration on the surface quality. They stated that the vibration of the tool can be useful to determine the surface quality and tool life in finish turning process. Lasota and Rusek [10] investigated the machine tool process conditions on the energy consumption and surface quality in turning operations. The authors developed a mathematical equation based on the cutting feed and the amplitude of vibrations between the cutting insert–workpiece. Choudhury et al.[11] examined the tool life, surface roughness and vibration in machining cast iron using different cutting parameters with ceramic cutting tools. They found that the vibration was increased with increasing cutting speed. vibration was not significantly affected at low depth of cut and flank wear of tool was increased.

Therefore, further experimental studies should be performed in order to collect detailed information about surface quality and relationships with spindle vibration in turning of aluminum alloy 7075. For this purpose, turning experiments were carried out using L_{64} full factorial design of experiments. Experimental results were analysed by using ANOVA and determined the most effective cutting parameters on spindle vibration and surface roughness. In addition, regression models were developed and compared to the measured and predicted results obtained from confirmation experiments for spindle vibration and surface roughness parameters.

Materials and Methods

Experimental studies were performed on a Taksan TTC630 CNC lathe machine with a maximum spindle speed 4000 rpm under dry cutting conditions. The four different depth of cuts, feed rates and cutting speeds values were used as a machining parameters to determine the effect on the machine tool vibration and machined surface quality of work part. The turning parameters and machining details are presented in Table 1. A coated cemented carbide cutting tool was used for the turning tests and every test was carried out a fresh cutting insert. The experimental Al 7075 workpiece was provided supplier in the cylindrical form with a diameter of 50 mm and a length of 100 mm. The workpiece was machined in the length of 60 mm to minimize the possible vibrations during turning process. The outer diameter of workpiece was pre-machined for a smooth surface at depth of cut 1 mm before the experimental studies to avoid the undesirable effect of the wavy structure and hard layer of material. The vibration of spindle was continuously monitored using a Pro vibro 303 vibration measurement instrument and average vibration value was calculated. A mitutoyo SJ-210 was utilized to measure surface roughness of machined workpiece (with a cut-off distance of 2.5 mm). Surface roughness measurements were done at five different places and maximum and minimum values were eliminated. Then, the arithmetic mean of these three values was taken and used for statistical evaluations. All experimental results for vibration and surface roughness were analysed and indicated on mean effect graphs by using Minitab statistical software. The experimental setup for spindle vibration and surface roughness measurements are given in Fig.1.

Table 1. Cutting variables used in the turning tests.

Parameters	Values
Lead angles (Degree), K_r	90°
Cutting speed (m/min), v_c	50, 75, 100, 125
Feed rate (mm/rev), f	0.1, 0.2, 0.3, 0.4
Depth of cut (mm), ap	1, 2, 2.5, 3
Workpiece dimension (mm)	Ø50 x 100
Nose radius (mm)	0.8
Cutting environment	Dry

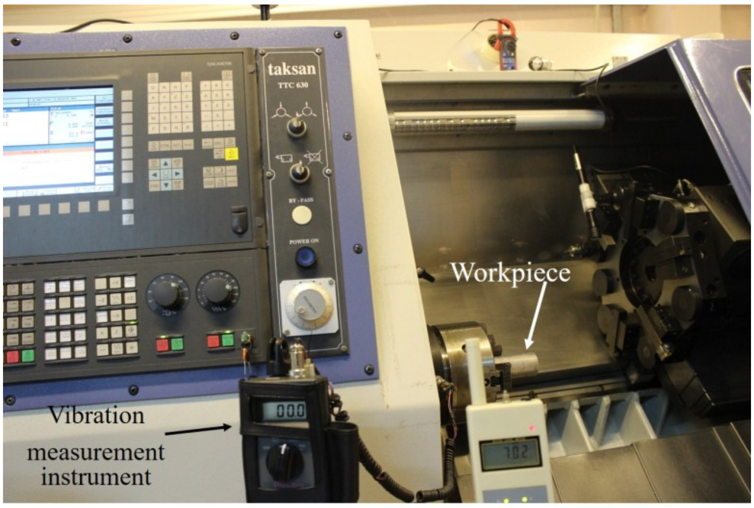

Fig. 1. Experimental setup for turning tests.

Experimental Procedure

In this experimental work, cutting feed, cutting speed and depth of cut were used to investigate the influence of the turning variables on the machine tool vibration and surface quality of the machined part. L_{64} full factorial experiments were chosen to evaluate the interactions between the independent parameters and output parameters, vibration and surface finish. The turning parameters and their levels are given in Table 1. Experimental outputs were evaluated depending on the signal-to-noise (S/N) ratio by using following smaller-the-better equation. We investigated the lowest surface roughness and vibration value. Therefore, smaller-the-better characteristic was selected to determine the optimal turning parameters for surface quality and machine tool vibration. Where *yi* is the measured value of machine tool vibration and surface quality for the i^{th} trials in that test, and n is the number of experiment in the tests, a higher S/N ratio is always preferred for the optimal results.

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

Experimental Results and Discussion

Machine tool vibrations and surface roughness values of machined part were measured during the turning of Al 7075 alloy and investigated the influence of turning variables on vibration and surface quality. The turning parameters and their main effects on vibration and surface finish are depicted in Fig. 2 and Fig.3, respectively. The optimal turning variables and levels are given in Table 2. The ideal cutting parameters for spindle vibration and surface roughness were determined the highest S/N ratios in the levels of cutting variable. According to the response table for S/N ratio in Table 3, the optimal turning variables for both vibration and surface roughness were specified as factor at depth of cut (A1) 1.0 mm, at cutting speed (B1) 50 m/min and at feed rate (C1) 0.1 mm/rev. the ideal machining combinations and *S*/N values are depicted with bold font in Table 3. The experimental results show that the significant correlation was observed between the spindle vibration and machined surface of the workpiece during the turning of Al 7075 (Fig.4). The surface quality of machined part was decreased with increasing spindle vibration. The spindle vibration was increased with increasing feed rate, cutting speed and depth of cut. The amplitude of vibration was changed with in the range of 0.1 – 0.45 m/s. As depth of cut and cutting speed increased, the amplitude of spindle vibration increased from 0.20 to 0.35 m/s and the machined surface quality of the workpiece was not affected significantly. However, the value of spindle vibration was remarkably increased from 0.1 to 0.45 m/s with increasing feed rate and the surface roughness value of workpiece increased from 0.76-4.90 µm due to the increasing cutting feed and spindle vibration.

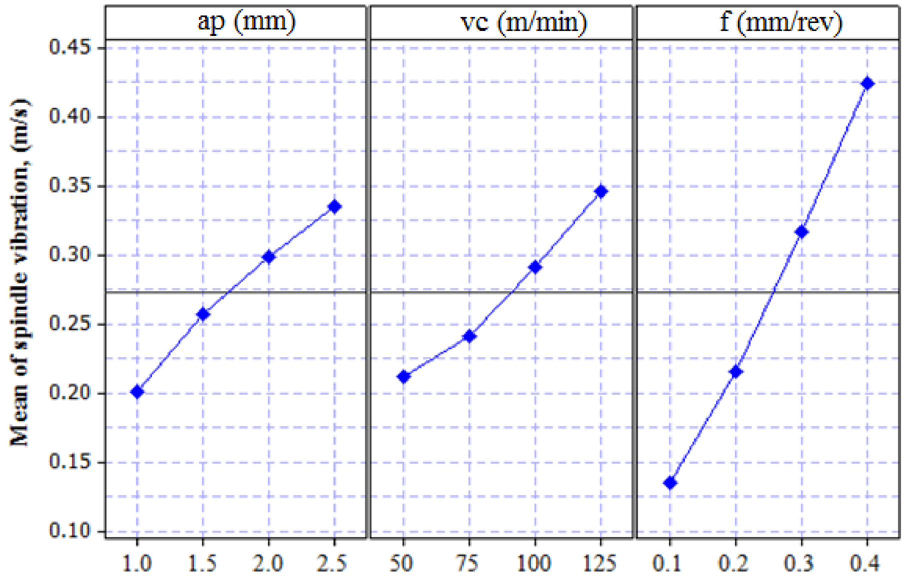

Fig. 2. Main effect of cutting variables on spindle vibration.

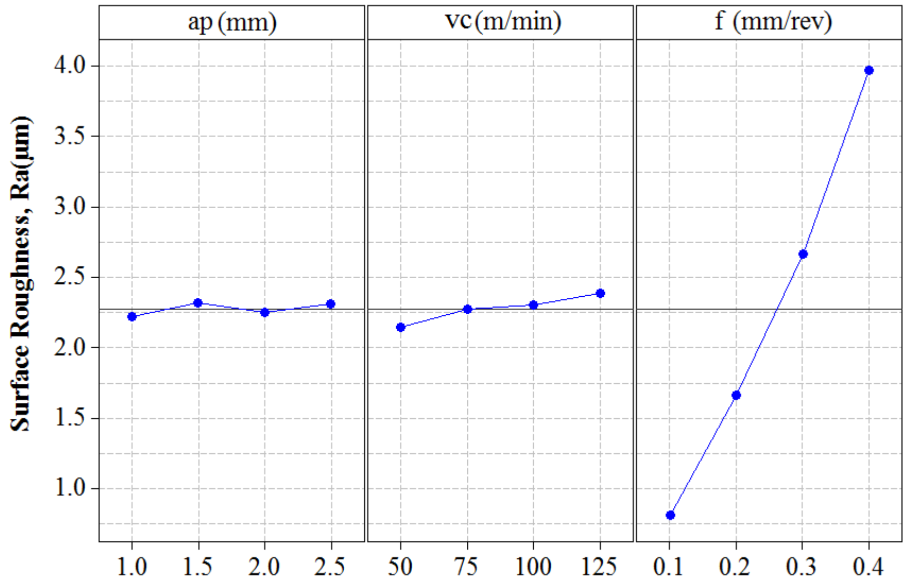

Fig. 3. Main effect of cutting variables on surface quality.

The cutting speed and cutting depth did not indicate a significant influence on the surface roughness of the workpiece. On the other hand, the surface quality was worsened with increases in the feed rates as expected.

Table 2. S/N ratios for vibration and surface roughness.

Level	a_p	v_c	f
1	**14.846**	**14.683**	**2.052**
2	12.939	13.530	-4.359
3	11.558	11.607	-8.482
4	10.493	10.015	-11.927
Delta	4.353	4.668	13.980
Rank	3	2	1

Level	a_p	v_c	f
1	-5.702	**-5.393**	**2.052**
2	-5.384	-5.596	-4.359
3	**-5.523**	-5.766	-8.482
4	-6.107	-5.961	-11.927
Delta	0.723	0.568	13.980
Rank	2	3	1

The measured test results were analysed by using an analysis of variance (ANOVA) to determine the influence of turning variables on the spindle vibration and surface quality during the machining of Al 7075. The spindle vibration and surface roughness values obtained from ANOVA are presented in Table 3. It is revealed that the cutting feed was the most significant machining parameter effecting the spindle vibration and surface roughness with percentage contribution of

65%and 94% respectively. The cutting depth and cutting speed were exhibited the same effect on the spindle vibration with a percentage contribution of 14%. However, surface quality was not statistically affected from cutting depth and cutting speed due to the higher feed rates used in the tests. Increasing cutting feeds caused the increasing spindle vibrations and eliminated the positive effect of cutting speed on the quality of machined surface. Hence, the surface quality was dramatically reduced with at higher feed rates resulting at higher spindle vibrations. The correlation between spindle vibration and surface quality are depicted in regression graph in Fig. 4 and regression equation are given in eq. 2.). R^2 value of the regression models for spindle vibration and surface roughness were computed as 92.9%

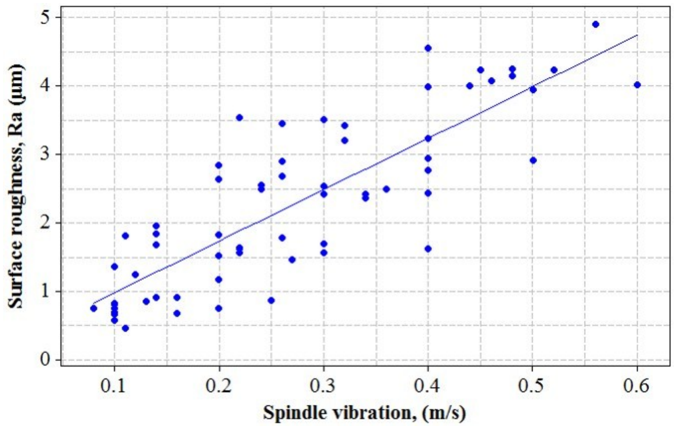

Fig. 4. Correlation between spindle vibration and surface roughness.

$$Surface\ roughness = 0.2263 + 7.524 \times Vibration \quad (2)$$
$$R - S_q = 70.2\%$$

Table 3. Results of ANOVA for spindle vibration and surface roughness.

Source	DF	SeqSS	AdjMS	F	P	Effect rate (%)
Vibration						
a_p	1	0.15842	0.158420	115.344	0.0000000	14%
Vc	1	0.16471	0.164711	119.924	0.0000000	14%
fz	1	0.75466	0.754661	549.461	0.0000000	65%
Residual Error	60	0.08241	0.001373			7%
Total	63	1.16020	0.359264			
Surface roughness						
a_p	1	0.0289	0.0289	0.33	0.565326	0%
Vc	1	0.4366	0.4366	5.05	0.028267	0%
fz	1	87.9692	87.9692	1018.16	0.000000	94%
Residual error	60	5.1840	0.0864			6%
Total	63	93.6186				14%

The regression models for spindle vibration and surface roughness are given following equations (3) and (4). R^2 values of the regression models for spindle vibration and surface roughness were computed as 92.9% and 94.46% respectively. Regression models were confirmed by validation experiments and confirmation experiments were carried out at depth of cut 3 mm, at cutting speed of 50, 75, 100 and 125 m/min and cutting feeds of 0.1, 0.2 and 0.3 mm/rev. Experimental and predicted results for spindle vibration and surface roughness were compared and illustrated in Fig. 5. The predicted values obtained from the regression models are very close to the measured values.

$$\text{Spindle vibration} = -0.284875 + 0.089 \times a_p + 0.001815 \times V_c + 0.97125 \times f_z \quad (3)$$
$$R - S_q = 92.9\%$$

$$\text{Surface roughness} = -0.670062 + 0.038 \times a_p + 0.002955 \times V_c + 10.4862 \times f_z \quad (4)$$
$$R - S_q = 94.46\%$$

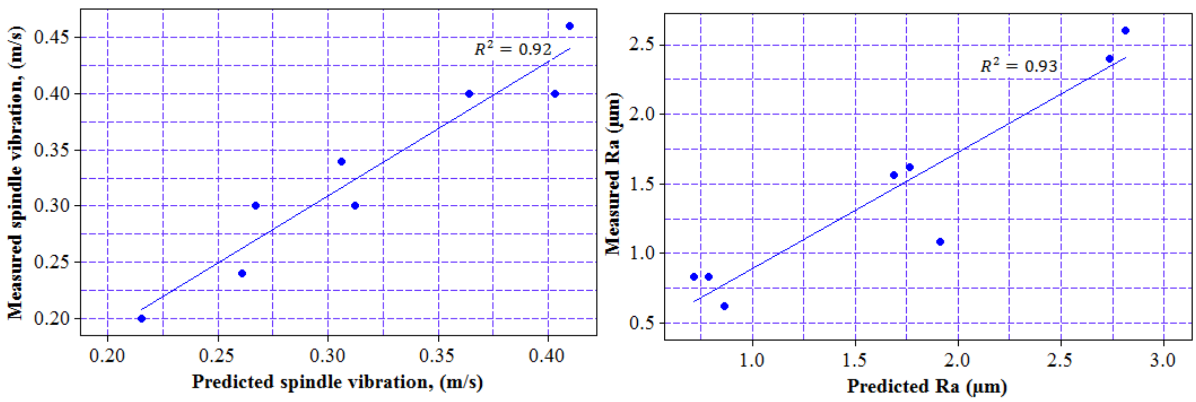

Fig. 5. Comparison of predicted and measured results for spindle vibration and surface roughness.

Conclusions

In this experimental investigation, the turning experiments were performed under dry cutting conditions and evaluated the influence of machining parameters on spindle vibration and surface quality. The effect of cutting variables on spindle vibration and surface quality was analysed by using ANOVA. The main observations may be summarized as follows:

- The spindle vibration and surface roughness were increased with increasing cutting feeds, cutting speeds and cutting depths.
- The optimum turning parameters for minimizing the spindle vibration and surface roughness values were defined from signal-to-noise ratios. It was observed the minimum values for spindle vibration and surface quality at lowest cutting variables used in the machining tests.
- ANOVA results show that the most effective machining variable for spindle vibration and surface quality was the cutting feed with a contribution of 65%and 94% respectively. The cutting depth and cutting speed affect the spindle vibration by 14% and did not show a meaningful influence on the surface quality.
- The prediction results exhibited a good relationship measured experimental results for spindle vibration and surface roughness R^2 =92.9% and 94.46% respectively.

Experimental results indicated that there is a correlation between spindle vibration and surface quality. Surface quality was reduced with increasing spindle vibrations.

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