Effect of Cutting Forces on Machining Process Parameters in Ultrasonic Vibration-assisted Turning

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ABSTRACT

In this work, the variation of the normal and friction forces on the machining process parameters in ultrasonic vibration-assisted turning are studied. The ultrasonic vibration-assisted turning process is more advantageous and efficient as compared to the conventional turning process. The dependency of the normal and friction forces at different workpiece velocities, frequencies and amplitudes are studied. It is found that the normal force and friction force varies linearly at low workpiece velocity whereas the normal forces are more effective at high workpiece velocity. On the other hand, the variation of normal and friction forces at different frequencies and amplitudes are followed similar trend. It was found that the presented results can be useful to analyze the cutting forces at different workpiece velocities, frequencies and amplitudes and also to optimize of the parameters for enhancing the productivity of the process.

Keywords – ***Normal force, Frictional force, Convention turning; Ultrasonic vibration-assisted turning, Aluminum alloy 6061***

I. INTRODUCTION

Ultrasonic assisted-vibration turning (UAT) is one of the most important processes to difficult-to-cut the material along with to achieve the better cutting performance and high surface finish. UAT process consists of piezoelectric transducer, booster and horn apart from the machining parts in conventional turning (CT). This made the process costly, however, with proper selection of the process parameters, it provides the significant advantages compared to CT. For example, Babitsky *et al*. (2003) observed that at UAT requires low cutting force, high surface finish and greater tool life and in the comparison of CT. In view of it, present study aims to carry out the parametric study on cutting force with the variation of workpiece velocities, frequencies and amplitudes of the tool considering the workpiece material is made of Al 6061 alloy.

A brief literature review of the earlier work is presented as follows. Skelton (1969) carried out experiments on ultrasonic assisted turning. They used magneto astrictive transducer to generate vibration and superimposed them on carbide cutting tool in both and radial and tangential direction. Weber *et al*. (1984) compared the surface roughness and tool life in conventional turning and ultrasonic assisted turning process. They used two different combinations of the tool and workpiece materials. Moriwaki *et al*. (1992) explored ultra-precision turning of glass and stainless steel by using crystal diamond as cutting tool. Masahiko and Murakawa (2001) developed a new rigid cutting tool system for the performing the ultrasonic assisted turning. They observed that machining of the hardened steel using the developed cutting tool system, chipping of cutting edge of tool reduces and surface finish is improved in both the intermittent and the continuous cutting mode. Ahmed *et al*. (2007) carried out a comparative study of the conventional turning and the ultrasonic assisted turning considering Inconel 718 as work piece material both in experimental study and finite element method (FEM). Chen *et al*. (2008) performed experimental study of conventional turning and ultrasonic assisted turning. Nath and Rahman (2008) carried out both experimental and theoretical study by different combination of process parameters with the cutting forces. Jamshidi and Nategh (2013) performed an experimental study of conventional turning and ultrasonic using Al 6061 as a work piece material. The cutting speed was 27 m/min keeping constant. The amplitude of 4–10 µm and frequency of 20 kHz was superimposed on tool in tangential direction in UAT process. Recently, Dixit *et al*. (2016) proposed a simplified analysis to assess the cutting forces in UAT through inverse estimation based on the measurement of cutting forces in CT at two specified cutting speeds.

In this work, a mathematical model developed by Jamshidi and Nategh (2013) is directly used here. A code based on the model of Jamshidi and Nategh (2013) was developed in MATLAB. However, a different methodology is employed (Dixit *et al*., 2016) to find out the averaged cutting force in UAT. Based on the developed code, a parametric study is carried out to discuss the significance of various process parameters.

II. A CRICTICAL REVIEW OF JAMSHIDI AND NATEGH (2013) MODEL

The mathematical formulation of Jamshidi and Nategh (2013) model employed the work of Zorev (1963) for CT process. Zorev (1963) developed the relation of contact and shear stresses as a function of tool-chip sticking length along with material properties. Based on the results of Zorev's model, Jamshidi and Nategh (2013) developed the methodology for finding out the contact and shear stresses in UAT process. The contact length between the tool and chip are calculated as a function of cutting time. Here, they introduced the contact length as a function of time equals to the product of the contact length and time function. The time function is estimated based on the experimentally measured cutting forces at different cutting speeds in CT. For the sake of completeness, the final form of expression of normal and friction forces are given as (Jamshidi and Nategh, 2013)

$$N_{\mathrm{UAT}} = \frac{bl_c\sigma_{\max}}{(t_4 - t_3)(y+1)}\int_{t_3}^{t_4} g(t)^{y+1} f(t)\mathrm{d}t \quad (1)$$

and

$$F_{\mathrm{UAT}} = \frac{\tau_{st} bl_c}{2(y+1)(t_4 - t_3)}\int_{t_3}^{t_4} f(t)g(t)^{(y+1)}\mathrm{d}t + \frac{\tau_{st} bl_c}{2(t_4 - t_3)}\int_{t_3}^{t_4} g(t)\mathrm{d}t \quad (2)$$

where $\sigma_{\max}$ is the maximum compressive stress at the tool rake face, τ_{st} is the shear stress, l_c is the tool-chip contact length, b is the width of the chip, l_c is the contact length between the tool and chip, y are the constant, $g(t)$ and $f(t)$ are the function of time, t_3 and t_4 are the time at which tool makes the contact and separates with work-piece, respectively. Considering the tool is vibrated along the longitudinal direction of the workpiece at certain frequency over the period of time, T; therefore averaged normal and friction forces are written as

$$N_{\mathrm{UAT}} = \frac{bl_c\sigma_{\max}}{(t_4 - t_3)(y+1)}\int_{t_3}^{t_4} g(t)^{y+1} f(t)\mathrm{d}t \quad (3)$$

and

$$F_{\mathrm{UAT}} = \frac{\tau_{st} bl_c}{2(y+1)(t_4 - t_3)}\int_{t_3}^{t_4} f(t)g(t)^{(y+1)}\mathrm{d}t + \frac{\tau_{st} bl_c}{2(t_4 - t_3)}\int_{t_3}^{t_4} g(t)\mathrm{d}t. \quad (4)$$

Jamshidi and Nategh (2013) already validated with their model with in-house experiment performed at different process parameters. It was found that the predictions of the theoretical model are to be less than 11% with the experimentally measured results.

III. RESULTS AND DISCUSSION

In this section, a detailed parametric study on normal and friction forces are carried out. The work-piece made of Al 6061 is considered. The workpiece material properties are taken from Jamshidi and Nategh (2013). The normal force and friction force are assessed at different work-piece velocities, frequencies and amplitudes.

3.1 Effect of work-piece velocity

The effect of work-piece velocity is studied on the average normal force, average friction force and the average friction coefficient while other machining parameters kept constant. Fig. 1 shows the variation of average normal force with the work-piece velocity. The computations were carried out using the experimental data reported in the paper of Jamshidi and Nategh (2013), to find out values *f(t)* and *g(t)* at different workpiece velocities. It is seen from Fig. 1 that the average normal force increases with the increasing the work-piece velocity. It is found that the work-piece velocity increases from 15 to 20 m/min, the average normal force increasing by 5.24%. If the work-piece velocity increasing from 20 to 27 m/min than the average normal force increased by 40.4%. However, if the work-piece velocity is increased from 27 to 33 m/min, the average normal force increases by 3.5%. If the work-piece velocity increases from 33 to 39 m/min, the average normal forces increases by 65%.

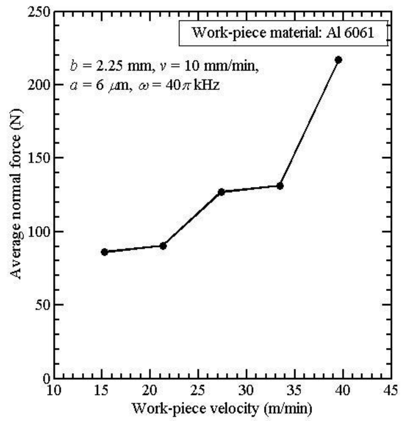

Fig. 1 Variation of average normal force with work-piece velocity

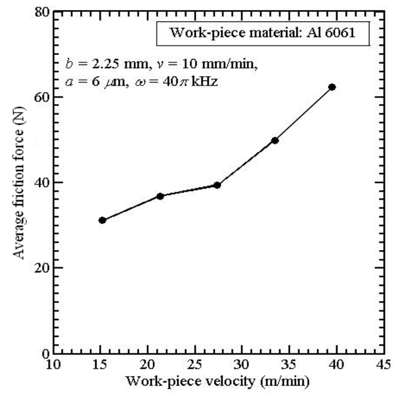

Fig. 2 Variation of average friction force with work-piece velocity

Fig. 2 shows the variation of the average friction force with the work-piece velocity. It is seen from Fig. 2 that average friction force increases with increasing in work-piece velocity. It is observed that that work-piece velocity increases from 15 to 20 m/min, the average friction force increases by 18.2%. If the work-piece velocity increasing from 20 to 27 m/min than the average friction force increased by 7%. The work-piece velocity is changed from 27 to 33 m/min, the average friction force increases by 27%. If the work-piece velocity increases from 33 to 39 m/min, the average normal forces increases by 25%.

3.2 Effect of frequency of vibrating tool

The effect of normal and friction forces with different frequencies of the tool is studied. Fig. 3 shows the average normal force reduces with increasing the ultrasonic frequency. It is observed that the average normal force is low at higher frequency of the vibrating tool in UAT. The similar trend is observed in the average friction force as shown in Fig. 4. However, the coefficient of friction slightly increases with increasing in the frequency of the vibrating tool. This is due to the more reduction in average normal force as compared to the average friction force.

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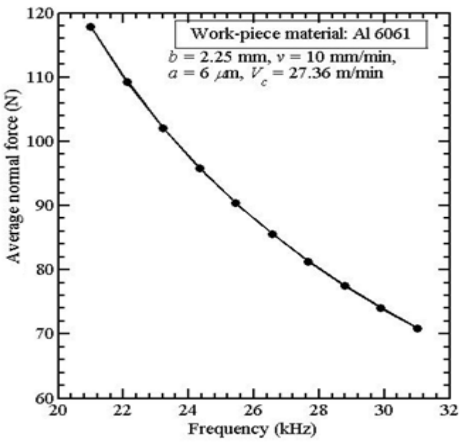

Fig. 3 Variation of average normal force with frequency of vibrating tool

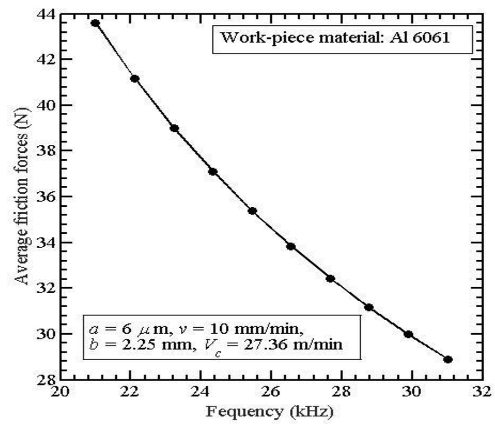

Fig. 4 Variation of average friction force with frequency of vibrating tool

3.3 Effect of amplitude of vibrating tool

The effect of amplitude of vibrating tool in UAT is studied to see the variation in the average normal force, friction force and the coefficient of friction at the tool-chip interface. Fig. 5 shows the average normal force reduces with increasing the amplitude of vibrating tool. It is observed that the reduction in the average normal force is more at low amplitude of the vibrating tool. The similar trend is observed in the average friction force case also as shown in Fig. 6. The coefficient of friction is more pronounced with increases in the amplitude of the vibrating tool.

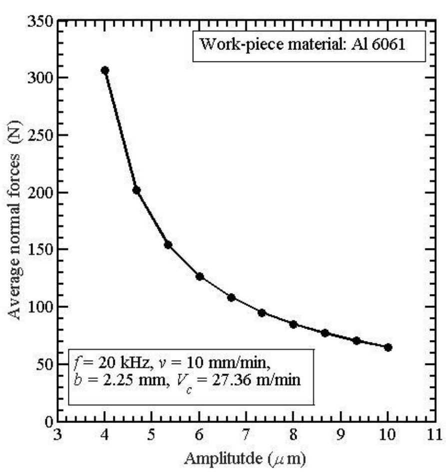

Fig. 5 Variation of average normal force with amplitude of vibrating tool

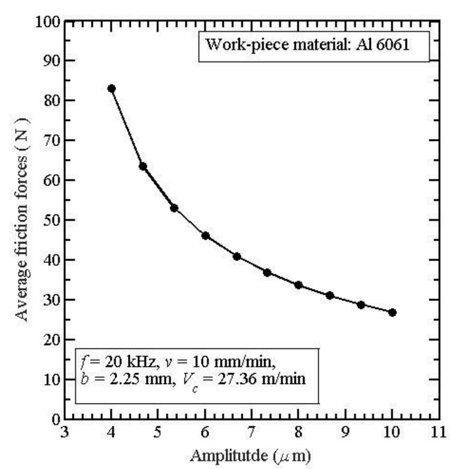

Fig. 6 Variation of average friction force with amplitude of vibrating tool

IV. CONCLUSIONS

In the present study, an analytical model for the estimating the average cutting forces and friction coefficient is briefly described. An in-house MATLAB® code has been developed for obtaining the normal force, friction force and the coefficient of friction at the tool chip interface. The parametric study has been carried out to see the effect of work-piece velocity, frequency and amplitude of vibrating tool. It is observed that the average cutting forces increases with increasing the work-piece velocity. Hence, the presented results can be useful for designer and/or control engineer to design the UAT process and also optimizing the process parameters. It is also planned to carry out the shop floor experiments in near future to find out the material properties and the coefficient of friction in UAT process by inverse analysis. Using inverse analysis, one can obtain the process parameters for the desired performance.

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