VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# A PERFORMANCE OF 2 DIMENSIONAL ULTRASONIC VIBRATION ASSISTED MILLING IN CUTTING FORCE REDUCTION, ON ALUMINIUM AL6061

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## ABSTRACT

This paper were investigate a performance of 2 Dimensional Ultrasonic Vibration assisted Milling (UVAM) toward Aluminium Al 6061. The focus is to find the performance of reduction of cutting force compared to the conventional machining in the industries shop floor. Due to the major effect of cutting force of production in industries, the excessive cutting force problem must be investigated deeply as it will cause shortens tool life and reduces the production rate. A scientific approach has been found in order to reduce the cutting force during machining which is integrating the ultrasonic concept into workpiece. The modelling of vibration cutting ratio has been simulated to find the time force contact and non-contact. Thus, less cutting force could be found. The ultrasonic vibration platform that generated by XY25XS from Cedrat Technologies is travelled in X direction as a feed movement. Thus, the X and Y axis vibration actuate along the workpiece for the machining process. The performance of UVAM in cutting force reduction found the superior benefits of UVAM is come from the alternating cycle's between tool and workpiece. The comparison between UVAM and conventional machining in reduction of cutting force is 32%. The potential of the UVAM tool wear and tool life will be discussed deeply in finding and next in the conclusion section.

**Keywords**: performance, ultrasonic vibration, cutting force, vibration ratio, tool life.

## INTRODUCTION

Metal machining is widely common area in industries as the products become sophisticated in profile and presently the rapidly increasing demand for it. The invention of new material integrated with superior mechanical and superior chemical properties driving the manufacturing sector to find a new method to sustain this issue. The product manufacturer always aiming a low cost, good quality product and high mass production in order to create satisfaction of industries. However, the problem of excessive cutting force during fabrication become serious issue from time to time.

During the machining, the contact point of tool between the tool and workpiece made up crucial problem next relating to the excessive cutting force. Shamoto and Moriwaki found in 1D UVAM that the peak cutting and thrust forces in VAM are seen to be the same as the continuous cutting and thrust forces with in conventional machining but the time contact of cutting force is slightly different as shown in Figure-1. As a result, the average of cutting force in 1D is tremendous reduced by comparing the graph.

Eliminating the excessive cutting force during machining will lead in reducing the temperature, prolong tool life and cost of the production rate.

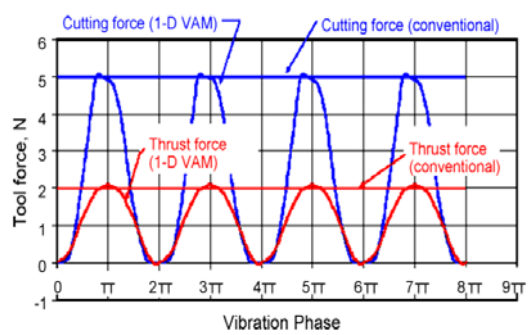



**Figure-1.** Comparison between instantaneous cutting force and thrust force between 1D UVAM and 2D UVAM.

There are many researchers and industrial design company that investigates the percentage of reduction while using this 2D UVAM concept. The percentage reduction or cutting force recorded show that the 2D UVAM is slightly reduced followed by 1D next in conventional machining. The percentage is calculated by measuring the Horizontal Speed Ratio (HSR). The maximum instantaneous tool forces in 2D VAM are smaller than the tool forces in conventional machining. As the frequency is increased and HSR becomes smaller, the peak tool forces decrease further been found (Moriwaki *et al*., 1994).

Figure-2 shows the comparison of the dynamic cutting between the 2D UVAM and conventional machining. There is an intermittent force acting signal detected on during machining in (blue line) showed the

amplitude and frequency were takes place to reduce the percentage of tool contact time thus simultaneously reducing of cutting force. The maximum intermittent cutting force recorded at 2.0N were dropped further till 0.0N as the tool is in non-contact period. The conventional cutting force (red line) showed the cutting force is sustained at the higher level approximately at 5.0N. Less cutting force has shown in the thrust force at maximum 1.0N on 2D UVAM compared to the conventional at the higher level at 2.0N respectively. Consequently, the performance of reduction in cutting force on 2D UVAM is better than the 1D UVAM in the average and the maximum point during the machining.

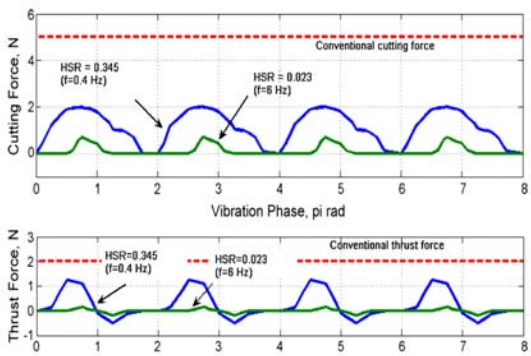



**Figure-2.** Comparison dynamic cutting (top) and thrust (bottom) forces in 2D VAM with conventional machining.

**Vibration cutting ratio**

To get a better understanding of 2D VAM, the ratio of the contact tool and non-contact tool to the workpiece must be studied in order to investigate the efficiency of the system, such as chip thickness, chip formation, etc. The frequency and amplitude are the most dominant factors for this ratio. However, the feedrate and spindle speed can make small changes which can provide the optimum chip removal efficiency.

Altintas 2006, explained that periodic loading causes cyclic mechanical and thermal stresses on the tool, causing the tool life to be shortened. Nevertheless, his model focused on the conventional cutting with the ratio of contact cycle in one. That means that for 100% of cutting time the rake face is in contact with the workpiece, which is hugely different from 2D VAM. Contact and non-contact tool ratios can be obtained by using this equation,

$$CuttingRat\ \ io = \frac{Time_{noncontact}}{Time_{totaltime}} \times 100\ \% \qquad (1)$$

Where, $Time_{noncontact}$ the sum of time that the rake faces or tool tip is not in contact with the workpiece. $Time_{totaltime}$ is sum of total time the tool is in cutting area. The higher Cutting ratio, the more time tool to separate into the workpiece that can be more benefit for chip removal efficiency, cutting force reduction, cutting temperature, extend tool life etc [Wang *et al.* 2002, Chern *et al.* 2006, Ahmed *et al*. 2007, Shamoto *et al.* 1999]. The impact and ploughing of tool tip penetrate the workpiece in 2D VAM can be predicted since it can be controlled by vibration and frequency to achieved a ductile region to improve surface roughness [Kim *et al.* 1998]. Therefore, the ratio of amplitude towards the feedrate motion must be identify to predict the cutting ductile region for the reason that the small forces of amplitude in controlled distance promoted a micro-crack and micro-fracture damage to the workpiece. Negishi 2003, performed cutting with 2D VAM and maintained ductile cutting to 3.5 µm depth into the silicon carbide. By taking this benefits into an account, the amplitude feed ratio has been introduced to investigate the relationship of amplitude affect into the feed per tooth can be mathematically define as,

$$AmpitudeFe\ \ ed = \frac{A_{\max\ chip}}{f_{tooth}} \qquad (2)$$

Where the $A_{\max chip}$ is the maximum amplitude of chip thickness and $F_{tooth}$ is feed per tooth. The trajectory of the tool point will reveal the regularity which is affecting the workpiece thus taken into account from the area of cutting. However, the oscillations number is controlled by three factors, $F_x$, $F_y$ and $n$, which can be expressed as:

$$\frac{60}{n} = \frac{M}{f_x} = \frac{N}{f_y} \qquad (3)$$

Where $M$ vibration time in 1 cutting cycle in X axis, $N$ is vibration time in 1 cutting cycle in Y axis and $n$ is a spindle speed. Increasing the frequency $F_x$ or $F_y$ will give more chances to tool vibrate into certain area of workpiece. This ratio is important to determine the chip thickness and shape producing at certain frequency.

**Cutting force and chip thickness**

Many researchers have modelled the cutting force in a different way and shown their accuracy by developing a chip thickness theory. For instance, Tlusty modelled based on the cutting trajectory. Merchant was taking a shear plane and slip-line field analysis to define the cutting force. Mohammad and Simon introduced ploughing coefficients, which are the ploughing forces per unit of ploughed volume by investigating the elastic recovery, and tool vibration including the effect of tool path trajectory.

The elastic recovery is identified using the instrumented scratch tests instead of the tool itself to void the tool breakage. However, in this section, the model of 2D UVAM for cutting force is investigated by looking at a trajectory of the tool path and predicting the chip thickness. From the chip thickness we are calculating the cutting force by merging the vibration effect into the original tool locus.

According to the Ding 2010, modelling of vibration assisted micro-milling, for calculating the cutting force in 2D vibration micro-milling, it is based on the chip thickness from the trajectory of the tool locus. The assumption is that the cutting force is proportional to the cutting area.

Figure-3, generated by Matlab programming, explaining the simulation of vibration ratio and tool path trajectory in the cutting mechanics in 2D UVAM, with effect of vibration frequency and amplitude, promotes that numerous cycles take place in a specified time interval. It is obviously explained by the fact that the cutting force is reduced when the tool point of the tool is in high force to remove the material in one single cut. In 2D UVAM, the vibration introduced non-contact within the tool and workpiece, helping to cut the material to smaller pieces while opposing the frequency and amplitude.

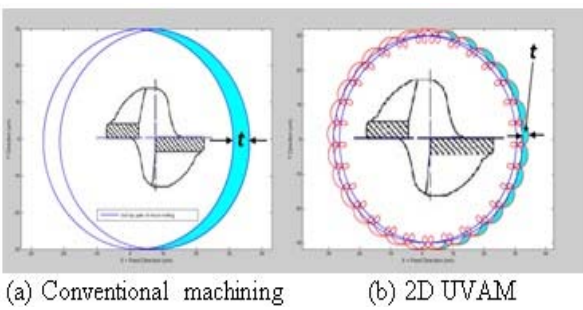



**Figure-3.** Difference of chip thickness affecting cutting force reduction.

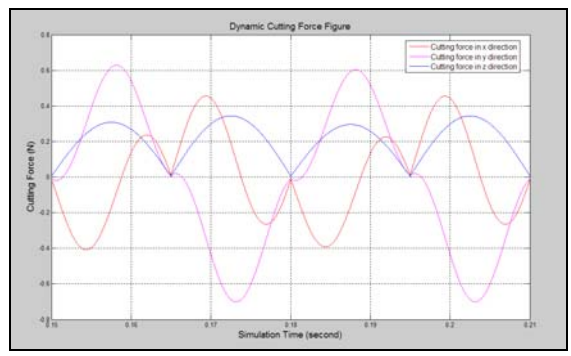
2D UVAM is shown to be the consequence of several mechanisms that modify chip geometry as well as interactions between the tool rake face and the chip as it is extracted (flush) from the workpiece. Figure-3 is a simulation program performed by Matlab. The simulation modelling was used for the same parameter conditions in spindle speed and feedrate. By composing a 2D UVAM it is obviously shown that the chip thickness and formation are changed and the chip thickness coloured by cyan. By comparing the "*t*" value in Figure-3, the chip (cyan) is represent the material being cut on the workpiece. There is significant founding in the thickness of chip thus related to the cutting forces. The tool forces have been reduced by the effect of the thinning eclipse motion to produce the chips.

Therefore, in 2D VAM, much smaller and shorter chips are produced, instead of a large and continuous chip as in conventional cutting. In addition, the tool motion operates with lower average force for a much larger cumulative distance in repetitive passes, compared to conventional machining in the same amount of time. In the same volumetric material removal, the work performed by 2D UVAM is therefore much more consistent than with conventional machining.

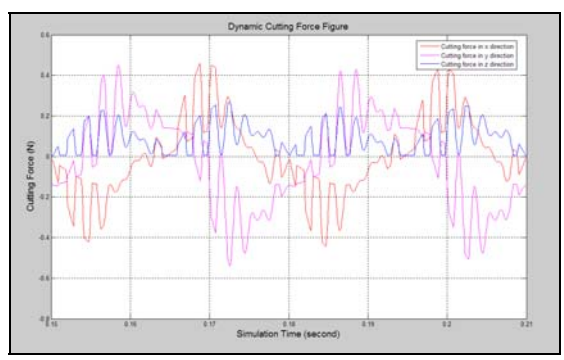
A comprehensive model for predicting 2D UVAM forces has not yet been published, but it appears that the dominant cause of tool force reduction depends on the geometry of the elliptical tool path. [Brehl *et al.* 2008].

The first theory in reducing the tool force is that the effect of the repeated overlapping tool paths results in chips that are thinner than the depth of cut in conventional machining. For the second, the effect of the tool path from the vibration intermittent loop, it reduced the tool forces because in the condition the tool velocity exceeding the chip velocity, producing a reversal of the direction of the tool-chip friction force and reduction or reversal of the thrust force.

Cutting force reduction has been explained in the simulated Figure-4 where (a) is conventional cutting and (b) 2D VAM. The parameter was the same, the only differences was opposing the vibration aid. Without vibration the maximum cutting force in the X, Y and Z are approximately 0.62 N, 0.43 N and 0.26 N respectively, but it is reduced to 0.42 N, 0.41 N and 0.21 N respectively with vibration assisted.




(a)




(b)

**Figure-4.** Comparison between VAM and conventional machining in cutting force.

The theory of reducing the cutting force in UVAM has been experimentally demonstrated by Shamoto and Moriwaki. Through their experimental study with a low frequency system operating at frequencies of 0 Hz to 6 Hz found that the instantaneous force (peak) cutting and thrust force are the same value as with conventional cutting. But there is a zero time period when the tool has no cutting force at all. It is believed the zero

cutting force condition came from the kinematic disengagement (tool separation) when there is non-contact between the tool edge and the workpiece. Shamoto and Moriwaki claimed a reduction of cutting force of approximately 30% to 40% from conventional machining.

In addition, Ahmed claimed that the increase in the vibration amplitude leads to a 52% decrease in the average cutting force in vibration assisted machining [10]. This is because of an increased part of the cycle of ultrasonic vibration without contact between the tool and chip.

An increase in the vibration frequency from 10 Hz to 30 kHz results in a 47% drop in the level of average cutting forces, which could be attributed to an increased velocity of the tool vibration. Hence, an increase in either vibration frequency or amplitude leads to a decrease in cutting force that is beneficial to increasing the accuracy and improving material removal rates.

**Ductile regime cutting in chip formation**

2D VAM has encouraged a small ploughing depth of cut that is very useful when cutting a hard and brittle material that has rapid crack propagation with low energy release and without significant plastic deformation. The ductile regime cutting will produce a plastic flow with very minimal subsurface cracking. It will induce a tool to cut a very small chip with fine formation in 1 μm depth or less. Ding and Rasidi have cut a hardened steel material HRC 58 and found the chip thickness is very fine grain, similar to flour, and that it is difficult to determine the thickness [15]. These are important findings related to micro-crack and micro-fracture in brittle material.

**An experimental case study**

The test were performed on a 2D VAM test bed with horizontal micro-milling air bearing spindle mounted on the solid metal table. 2 flutes 1.0 mm endmill have been used to cut the mild steel and aluminium T6 as a workpiece. The workpiece 30 mm × 30 mm × 1.5 mm was fixed in the vibration platform through jig bolted into the workpiece holder. The cutting force measure by using dynamometer located in AMRG of Universiti Tun Hussein Onn Laboratory. The cutting trial was running with dry condition.

## CONCLUSIONS

From this paper we can conclude the 2D vibration assisted milling is obviously shown to promote a distinct advantages compared with conventional machining methods over a wide range of precision machining application whether in macro and micro. It is founding the major improvement in reduction cutting force, reduction in temperature, extended tool life, discontinuous, thinning and changes of chip formation and improving the surface roughness came from the effect of engaging and disengages of the tool related to the workpiece. The creating of gap between the rake face and workpiece also play important effect to this major improvement. These mechanics advantages include:

- Less time contact between cutting tool and workpiece promote less cutting force.
- The movement of tool point in ellipse motion altered the effective rake angle toward the workpiece. Greater rake angle reduce the cutting force.
- Alternating cycle motion by the amplitude allows cutting force reduction whilst increased the displacement of tool point, therefore MRR will be increased by taking into account of amplitude displacement.
- Frequency and amplitude helps tool edge to cutting cut in ductile region efficiently.

## ACKNOWLEDGEMENTS

The authors would like to thank Minister of Education for Research Acculturation Grant Scheme (RAGS), Advance Machining Research Group (AMRG) Universiti Tun Hussein Onn Malaysia, (UTHM) and to Cedrat Technology SA for providing the piezo-actuator system.

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