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Research Paper

An experimental study on cutting tool wears in turning process through control of tool vibration

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ABSTRACT: *This paper presents an experimental method to determine the wear amount and tool life of the cutting tool during turning by controlling the vibration parameters of the tool. The experimental process was carried out by dry machining and overflows machining with solution mixed 5% Emulsion with cold water. After each machining session about 9 minutes, stop the machine and determine the amount of tool wear. At the same time, the tool vibration is collected to the computer according to the machining time for analysis. The results show that the vibration parameters of the cutting tool (velocity, acceleration and vibration amplitude) accurately reflect the three typical wear stages of the tool. This is an option to evaluate and control the durability of the tool with a smaller and simpler investment cost than with the use of force sensors to determine the durability of current tools.*

KEYWORDS: *Wear, Dry machining, Overflow, Vibration, Tool life.*

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I. INTRODUCTION

Wear of cutting tools in machining processing greatly affects productivity, quality as well as product cost. Wear of cutting tools is a complex process, occurring with mechanical, physical and chemical phenomena at the contact surfaces [1],[2],[3]. When the tools are worn, the shape and geometry of the cutting edge change will cause vibration phenomena, adversely affecting the cutting process, such as reducing machining efficiency, reducing geometrical accuracy and increasing surface roughness of the work piece [3],[4],[5]. Wear of cutting tools also reduces durability and increases machining time due to tool replacement, which increases production costs [5],[6]. In addition, tool wear increases cutting forces, causes vibrations for the technological system, and affects not only the accuracy of the product, but also reduces the life of the machine [1],[2],[3],[4],[5]. In order to limit tool wear during the machining processes, technologists are focusing on researching and using cutting tools with high durability and high heat resistance, cutting tools are sprayed on the surface, changing other geometry factors of the tool, using different lubrication methods…etc.

There have been many studies to determine, predict and control tool life to improve working conditions to improve product quality as well as machining efficiency. For example, determining through wear and force on the tool [6], using mathematical statistical methods to build regression function [7],[8],[9], simulation [4],[10],[11],[12],[13]... Recently, a number of studies have begun to conduct direct control of the wear process [14],[15]. Modern tools such as sensors are attached to the machining system, data is collected and stored on computers for analysis, which can accurately predict wear and tool life. This is also the inevitable trend of the current industry 4.0.

This paper presents an experimental study on the effects of overflow lubrication and dry machining on cutting tool wear during turning process. The wear progress of tool insert is controlled through tool vibration. Simultaneously, the changes in the geometry of the edge cutting were recorded, using optical microscopy.

II. EXPERIMENTAL DETAIL

The experimental setup is shown as shown in Figure 1. The machine tool used in the experiment process is a MASCUTMA1840 Universal Lathe (Taiwan). The workpiece (3) is clamped at one end on the chuck of the lathe (1). The other end of workpiece is attached to the center point (4). The turning tool (6) is mounted on the tool holder and moves along the length of the workpiece to machine the entire surface of the workpiece. Sensor (5) is used to measure the vibration of the turning tool. Nozzle (2) is used to supply coolant to the cutting zone. The carbide tungsten inserts (TiN coated) of the Kyoceda, Taiwan having CNMG 120408 PQ 432 (120 x 120 x 30, in mm) code are used in this study, as shown on Figure 3. The inserts have other geometric parameters, including: $\alpha = 6°$, $\lambda = -6°$ and $\gamma = -6°$.

The workpieces used in the experiment processes (Figure 2) is a solid cylinder with a diameter of Ø55 mm and a length of $L = 350$ mm, which has been machined for the tool outlet and drilled with a center hole. The workpiece material is 90CrSi steel with the composition as depicted in Table 1. Before experiment, the workpiece samples were quenched, the hardness reached 50-52HRC.

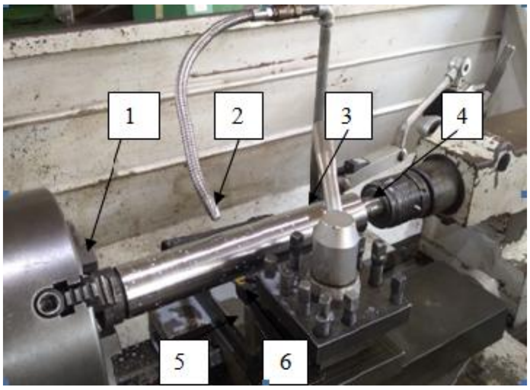


Figure 1: Experimental setup
1- Chuck, 2- Nozzle, 3- Workpiece, 4- Center point, 5- Sensor, 6- Turning tool

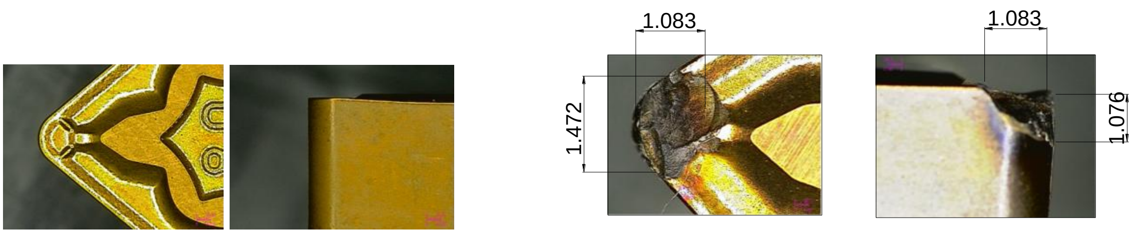
Figure 2: The photo of the workpiece used for experiment

Figure 3: The photo of the turning tool

Table 1. Chemical composition of 90CrSi steel.

Chemical element	C	Si	P	Mn	Ni	Cr	Mo	V	Cu	W	Ti	Fe
Content (%)	0.8	1.1	0.2	0.5	0.03	1.1	0.02	0.14	0.28	0.17	0.02	Balanced

To evaluate the effect of cooling lubrication on tool wear through vibration, dry turning and overflow turning were performed and compared with each other, respectively. The coolant used is a mixture of more than 5% emulsion mixed in water. The cutting parameters used in the machining process, include: cutting speed $V = 80$ m/min; depth of cut $t = 0.1$ mm; longitudinal feed rate $S = 0.15$ mm/rev.



(a) The new insert

(b) The insert after 9 minute cutting

Figure 4: The photos of the inserts: (a) new one; (b) worn one

Corresponding to each turning process, every 9 minutes machining time will stop machining and take a picture of the cutting edge to assess the amount of wear. Simultaneously, the surface roughness of the front and back faces of the cutting tool is determined. Besides, the vibration parameters of the cutting tool, such as vibration velocity, vibration acceleration and vibration amplitude are collected and processed. Due to the limitation of the length of the workpieces, the turning process is repeated every 3 minutes. Therefore, the results showing the vibration velocity, vibration acceleration and vibration amplitude are shown by the number of feeds on the figures from 5 to 8, respectively.

The wear of cutting tools is checked periodically, using microscope KIM450 (ARCS, Japan). The microscope has a linear scale of 0.5μm on the XYZ axis, an optical magnification of the objective from 0.7 to 4.5 and 2 illumination modes, including: transparency and surface projection. Figure 4 shows the photos of new insert and worn insert, taken by microscope KIM450.

III. RESULTS AND DISCUSSION

Table 2 presents the results of measuring the face and flank surface wear of the cutting tool by machining time, showing the progress of the wear process of the face and flank surface of the insert.

The figures from 5 to 9 show the plots of the evolution of the velocity, the evolution of the acceleration, the evolution of the amplitude and standard deviation of amplitude vibration, respectively. We can see the obtained images of vibration when turning.

The vibration value is stabilized after about 9 minutes of cutting (i.e. the 3rd feed in figures), during this initial time the cutting tool wears out quite quickly due to the wear of undulating peaks on the surface [3]. During this stage, the cutting tool wears out due to unit pressure in the large cutting zone, the face of the tool insert is continuously in contact with the chip, and the flank of the tool is always in contact with the machined surface. The undulating peaks on the tool surface are quickly flattened. Therefore, the wear rate of this stage is large.

Table 2. The results of measuring the face and flank surface wear process

No	Time (s)	Dry turning		Overflow turning	
		Hs	Hb	Hs	Hb
1	9	0.435	0.521	0.470	0.576
2	18	0.748	0.822	0.632	0.761
3	27	0.783	0.906	0.649	0.776
4	36	1.002	0.923	0.729	0.800
5	45	1.106	1.103	0.983	0.901
6	54	1.490	1.355	1.083	1,076
7	63	1.610	1.503	1.106	1.103
8	72	0000	0000	1.310	1.344
9	81	0000	0000	1.430	1.478

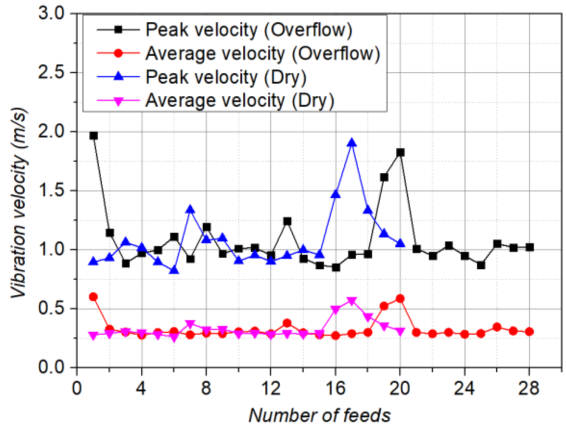


Figure 5: Vibration velocity value of turning tool

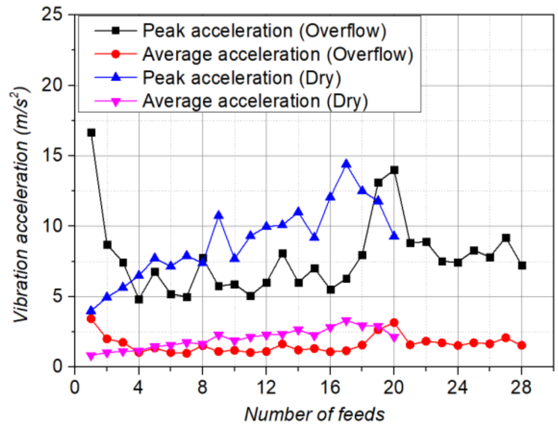


Figure 6: Vibration acceleration value of turning tool

The stability of the cutting process is extended from 9 to 45-minute (i.e. from the 3rd feed to 15th feed in figures) in dry machining. Meanwhile, when machining with cold lubrication, the stability of the cutting process is longer up to 54 minutes (i.e. up to the 18th feed in figures). Thus, when machining with cold lubrication, the tool life has increased by 9 minutes compared to dry machining. However, during this time, when observing the acceleration plots, it is easy to see that when dry machining has larger vibration acceleration, especially comparing the peak acceleration value. Acceleration in dry machining spikes up before now because dry machining tools wear more due to coating disintegration resulting in greater vibration. This stage corresponds to stable wear conditions, such as: large contact area, unit pressure is smaller than stage 1, stable coefficient of friction. Therefore, the wear rate of the tool is relatively even and slow, this period usually corresponds to the reasonable amount of wear Hs of the tool and the time corresponding to it is chosen to determine the tool life.

When dry machining passes 45 minutes and when lubricated machining cools past 54 minutes, the amount of wear increases rapidly. However, when machining with cooling lubrication, the amount of wear increases more slowly. This stage corresponds to unreasonable cutting conditions, that is, the geometrical parameters of the cutting tool change large and unreasonable - negative posterior angle. This leads to increased shear and friction forces, and an increase in the coefficient of friction. As a result, the tool wear rate increases rapidly, which destroys the tool if cutting continues. The tool is no longer able to work, in order to continue machining, it must be sharpened.

Stability at shear is observed over standard deviation. The larger the standard deviation is, the smaller the reliability of the value get. Which means that the greater the stability of the measured value at that time. The assessment of cutting tool wear can be assessed by standard deviation, when wear occurs, the standard deviation value will skyrocket. The reason for that phenomenon is that at the time of wear, the cutting force is not stable and the profile and size of the tool are also unstable, leading to unstable vibration. The vibration value changes continuously according to the change of the input factors. For cold-lubricated machining, due to small friction and small cutting force, the tip is relatively freer than in the case of dry machining. As a result, the vibration values are larger and the tip stability is also lower, so the standard deviation is larger in dry machining. It is expected that this phenomenon will change if machining with a sufficiently large depth of cut.

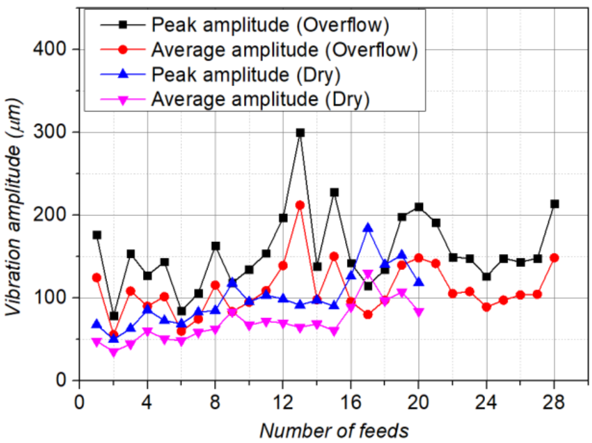


Figure 7: Vibration amplitude value of turning tool

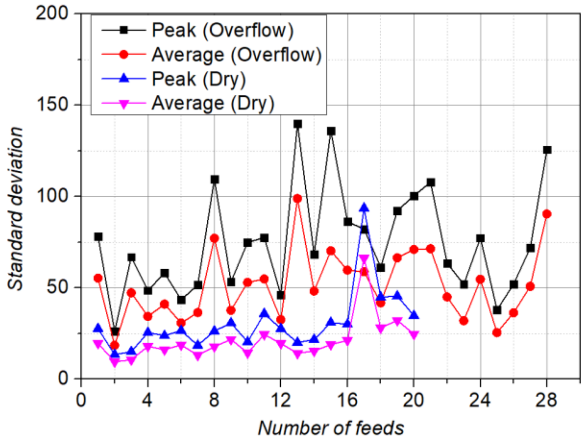
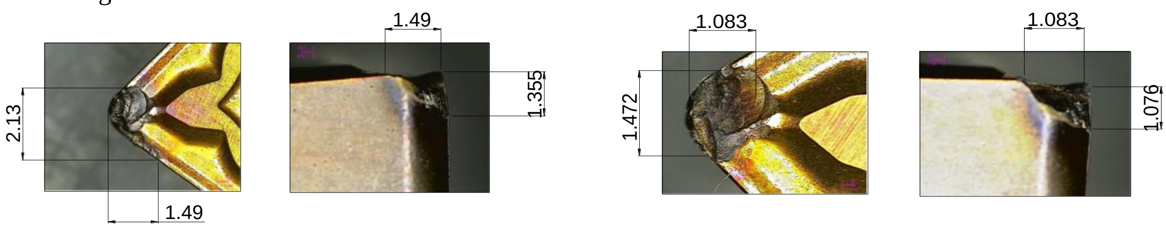


Figure 8: Standard deviation when measuring the vibration amplitude of the turning tool

From 54 min onwards, the amount of wear developed rapidly in the auxiliary edge, as shown in Figure 10. It is easy to see that the amount of tool wear when dry cutting is much larger than that when overflow machining.



(a) dry machining (b) overflow machining

Figure 10: The photos of tool inserts after turning 54 minute

IV. CONCLUSION

Lubrication – Cooling greatly affects cutting tool wear during metal cutting. Tool wear and vibration are two quantities that are linear to each other. Measuring tool wear can determine vibration during cutting and vice versa, knowing the value of vibration can determine tool wear. When the vibration increases rapidly, the cutting tool is worn and needs to be replaced or re-sharpened for the next cutting process. These results can be

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applied to production to accurately predict the life of the cutting tool through vibration, thereby helping to determine the time it takes to change the tool to proactively reduce machining time, increase machine life and contribute to product cost reduction.

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