MATEC Web of Conferences **169**, 01036 (2018) https://doi.org/10.1051/matecconf/201816901036
IMETI 2017

Application of passive damping fixture to the improvement of CNC drilling

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Abstract. High precision and high efficiency are the essential competition conditions for multi-axis machine. However, machine vibration problems are always plagued by equipment manufacturers. This study focuses on solving or eliminating the multi-angle drilling vibration of processing machines. By the design and experiment combining CNC multi-axis machine tools with vibration tables, the surface roughness in the multi-angle drilling holes is discussed for the reference of the industry or the academia. The results indicated that adding proper vibration factors could effectively improve the bore surface roughness and smoothness. Roughness *Ra* with the vibration interval time 0.5 sec, could improve the surface roughness 48.95% of the processing hole, comparing to it without vibration. Besides, the resonance phenomenon disappears at the feed to generate good effect. It is expected to reduce various vibration problems faced by processing with machine tools in order to enhance the international competitiveness of processing tool manufacturers.

1 Introduction

Cutting has played a critical role in the machinery-manufacturing environment. However, various countries have actively improved the processing methods with the constant development and advance of high-tech industry. Moreover, Rahman and Kumar [1] experimented and analyzed the micro-milling of pure copper, improved the experimental result through the analyses of cutting force and chip types, and observed the wear of micro-mills. Nouari*et al.* [2] discussed drills with three different materials and distinct coating materials to analyze the tool life, the quality of hole, and the surface roughness of hole wall of the three drills in the aluminum alloy (A2024) drilling. The results revealed that B-type drill presented better performance than the other two types, aiming at above three processing properties. Lee *et al.* [3] utilized a micro-mill (with the diameter 254μm), similar to drilling, for processing micro-holes. It was found that the tool life reduced with increasing burr height. The characteristics of burr formation were therefore discussed and the processing parameters were controlled for the minimum burr formation and further improving the tool life.

Masahiko and Masao [4] investigated a combination of countermeasures to prevent the chipping of the edge of a cutting tool. The results indicated that the chipping of the cutting edge can be effectively prevented and a good surface finish obtained by both continuous and intermittent cutting modes when cutting hardened steels. Altintas and Weck [5] collected and organized various studies to describe flutter principles, various processing modeling and simulation, and suppression tactics.

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There has not been a usable damping method for tapping, broaching, and gear rolling. Marui *et al.* [6] mentioned that the damping of a tool system came from micro slide, the damping of the cutting tool itself, and the friction with the air during vibration. They therefore inserted thin sheets between cutting tool and tool slide and inside the cutting tool in order to enhance the friction force and further promote the damping of the cutting tool system.

From above literatures, a lot of domestic and international experts and scholars have studied and concerned about the improvement of CNC processing industry. However, little research focuses on CNC vibration, and most of them pay attention to the spindle, but rare on the vibration of CNC processing trays. Consequently, this study stresses on the vibration of processing trays in order to provide reference for domestic and international experts and scholars and the industry with more complete processing parameters.

2 Basic theory

2.1 Vibration

The use of machines is inevitable in human life, and the operation of each machine would generate vibration. The major factors in machine damage are mainly resulted from resonance or close-resonance of machines. Such situations might occur in the high-speed operation of machines or the starting and stopping of a machine. Such resonance stress would gradually accumulate to appear cracks as well as increase and expand such cracks to result in machine damage. In this case, the subject of mechanical vibration becomes critical to evaluate the life of machine element in advance and to ensure the life limit of a machine. To understand the factors in machine damage, it needs to understand the reason of machine vibration and to know the design of vibration control.

Moreover, the factors in mechanical system failure or misalignment are the over vibration and resonance of elements and systems. The natural frequency and external stimulation frequency of mechanical structure vibration would appear resonance to result in excessive deformation and system failure. As vibration would cause violent effect on mechanical structure, vibration test has been listed as a standard design step in the design and development of most engineering systems.

2.2 Damper

The principles of damper commonly used in academia and the industry are described as below.

2.2.1 Active damper

An active damper is equipped a sensor to monitor the processing situation. When there is vibration, signals are sent to the actuator which gives an opposite force to the cutting tool and vibration to offset the vibration. As sensor signals need to be immediately handled and transmit orders back to the actuator, the speed to deal with signals and the reliability of vibration judgment are considered critical. It is the difficulty in the active damper design. Besides, the actuator force would affect the damping effect; weak force would not appear effect, while strong force might become the vibration source. It therefore requires experiment confirmation or detailed simulation.

2.2.2 Semi-active damper

Similar to active dampers, a semi-active damper monitors the processing situation with a sensor, but the rigidity and damping characteristic of the cutting tool would change to offset vibration when the vibration occurs. To achieve such an objective, electrorheological and magnetorheological fluid or piezoelectic materials are utilized for changing the properties to change the vibration stability diagram so as to avoid the vibration are and prevent vibration from occurrence.

2.2.3 Passive damper

In comparison with active dampers, a passive damper reveals the advantages of simple structure, low costs, and easy installation. Nevertheless, it could not randomly change to match the processing environment that the effect is worse than an active one. Although some dampers present tunable mechanism to adjust the natural frequency or damping of dampers, it might not be properly adjusted because of unknown field processing parameters.

3 Research methodology and processing step

By summing up the above discussion and theories, the relationship between cutting and vibration is the primary part to control the machining precision that the relative technology R&D and problem overcoming are worth further discussion. The research process is referred to Fig.1 and described as below.

(1) To search data related to CNC comprehensive processing machine, vibration table, and cutting, according to the speed and feed and cutting tool materials, to establish a database.
(2) To cultivate the vibration factor and the use technique of CNC comprehensive processing machine.
(3) Precede the use proficiency of NX modeling and processing modules.
(4) Match and communicate software and hardware with vibration table, CNC comprehensive processing machine, and NX software.
(5) Collect cutting data with cutting speed and feed matching with cutting tool materials.
(6) Calculate suitable cutting values for seriously worn cutting tool materials, feed speed, and vibration frequency by matching with cutting data.
(7) Compare the analysis result and the entity, and revise the cutting and vibration table parameters.
(8) Select cutting numerical control factors for the optimization and influence analyses.
(9) Compare the cutting tool life before and after the optimization and the surface precision of workpiece.

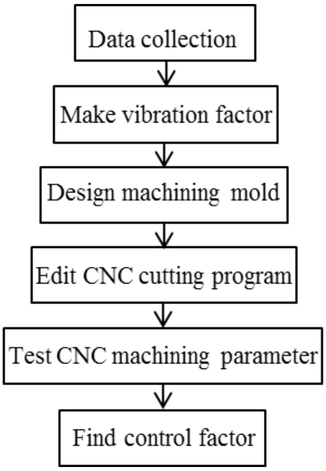


Figure 1. Experimental flow of CNC drilling matching with passive damping fixture.

The relevant equipment and the parameters are described as following.

(1) CNC multi-axis processing machine

CNC multi-axis processing machine developed by Tongtai Machine & Tool Co., Ltd. is used as the machine table in this study.

(2) Vibration table

The vibration table is produced in this study; the designed passive damper entity is shown in Fig.2. The interior mechanism is composed of base, magnetic metal table, electromagnet, four support columns, and damping spring. The motion principle reveals to directly drive the mechanism, through electromagnet power-on, to form the up-down vibration of the spring.

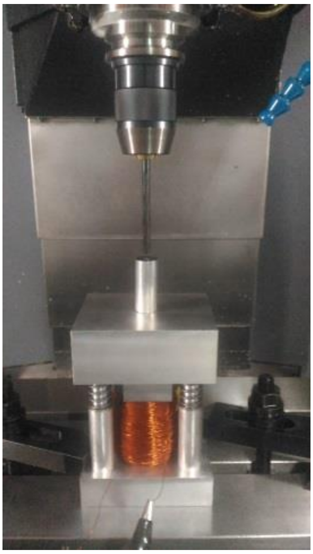


Figure 2. Passive damper entity.

4. Result and discussion

In the beginning of this study, the borehole workpiece without vibration source is produced; the finished appearance and the surface roughness are shown in Fig.3. The mean *Ra* , *Rmax*, *Ry*, and *Rz* after four measurements are 3.379, 39.247, 18.517, and 13.846μm. Since there is no vibration frequency, the processed bore surface roughness is not favorable, the value measured by the surface measuring instrument is rather high, and the surface appears irregular processing lines and unsmooth conditions.

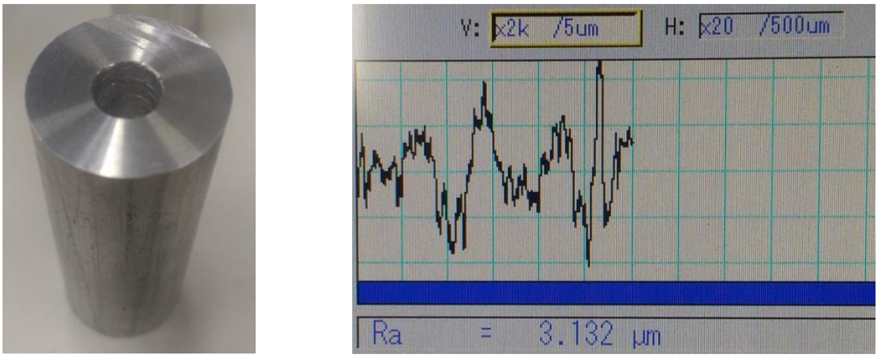
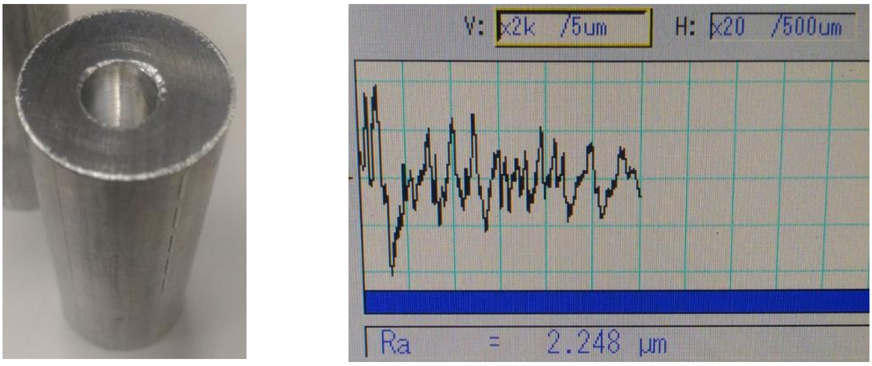


Figure 3. Analysis result of non-vibration factor finished product and surface roughness.

A PLC programmable control device is further utilized for setting various vibration frequency intervals 0.2 sec, 0.5 sec, 1 sec, and 1.5 sec. When the bottom electromagnet of the vibration platform generates magnetic force with 0.2 sec transmission frequency and further generates vibration force and an aluminum alloy rod is processed under the same processing parameters, the acquired finished processing appearance and bore surface roughness are shown in Fig.4. The mean *Ra* , *Rmax*, *Ry*, and

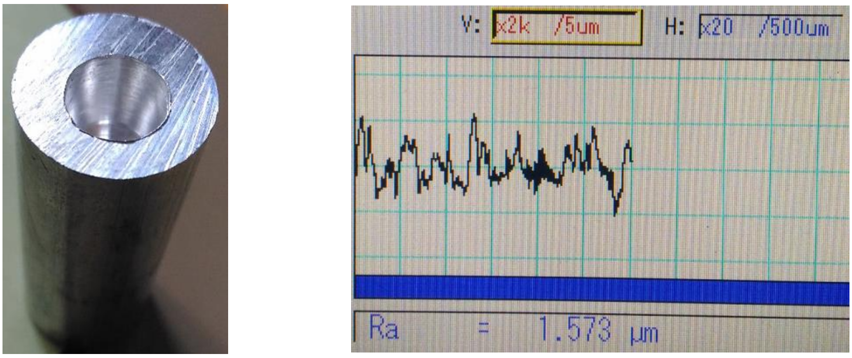
*Rz*appear1.992, 25.798, 12.220, and 9.583μm. Since a 0.2 sec micro vibration factor is opened for this finished product, it is observed that the bore lines are even, the bore smoothness is improved comparing to the finished product without vibration, and the measured *Ra* data are reduced a lot than those without vibration. Apparently, the bore roughness is actually improved. However, it is worth noticing that the borehole feed processing would slightly generate resonance phenomenon to result in hole cracks as the vibration frequency is opened before the borehole processing. Such a phenomenon disappears after drilling for about 1 sec. The feed for the borehole processing therefore presents obvious crack marks, Fig.4.

Processing aluminum alloy rod material by opening 0.5 sec transmission frequency through PLC to acquire the finished processing appearance and the bore surface roughness, Fig.5, the mean *Ra*, *Rmax*, *Ry*, and *Rz*show 1.725, 28.885, 11.443, and 8.254μm. In comparison with non-vibration and 0.2 sec finished products, it is obviously that the 0.5 sec drilling bore lines are evener than 0.2 sec ones, the bore smoothness and *Ra* data are better than those of non-vibration and 0.2 sec ones, the cracks generated by the resonance phenomenon in the drilling feed disappear, while *Rmax* data of 0.5 sec ones are higher than those of 0.2 sec ones. It requires further research.


V: x2k /5um H: x20 /500um

Ra = 2.248 μm

Figure 4. Analysis of finished product with 0.2 sec vibration frequency interval and surface roughness.


V: x2k /5um H: x20 /500um

Ra = 1.573 μm

Figure 5. Analysis of finished product with 0.5 sec vibration frequency interval and surface roughness.

1.0 sec transmission frequency is further opened for processing the aluminum alloy rod material. The finished appearance and the bore surface roughness are shown in Fig.6. The mean *Ra* , *Rmax*, *Ry*, and *Rz* are 2.170, 37.377, 13.390, and 10.859μm. The results of the experiment finished product are not as good as expected. The bore drilling lines are obviously improved, and *Ra* data are lower than those without vibration; however, obvious uneven lines appear and the resonance phenomenon is more obvious at the feed. The crack marks at the initial drilling feed are therefore larger and the difference is obvious. Such a phenomenon gradually disappears after processing for 1 sec, when the successive bore lines become evener.

Finally, the finished appearance and the bore surface roughness with 1.5 sec transmission frequency through PLC are shown in Fig.7. The mean *Ra*, *Rmax*, *Ry*, and *Rz*appear 2.830, 37.972, 16.770, and 11.025μm. With the experiences in 1.0 sec experiment finished product and surface roughness, the 1.5 sec finished product is the same as expected. The lines after drilling are similar to those without vibration, the smoothness is about the same as it without vibration, and Ra data are even worse than those without vibration. Moreover, the resonance phenomenon generated in the drilling feed is so larger that the feed port of the finished product generates larger crack marks. The successive bore processing therefore could not match with the vibration frequency and further appear opposite effect.

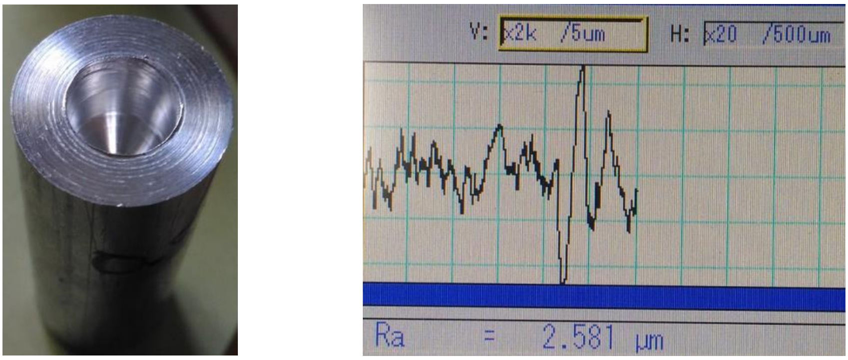


Figure 6. Analysis of finished product with 1.0 sec vibration frequency interval and surface roughness.

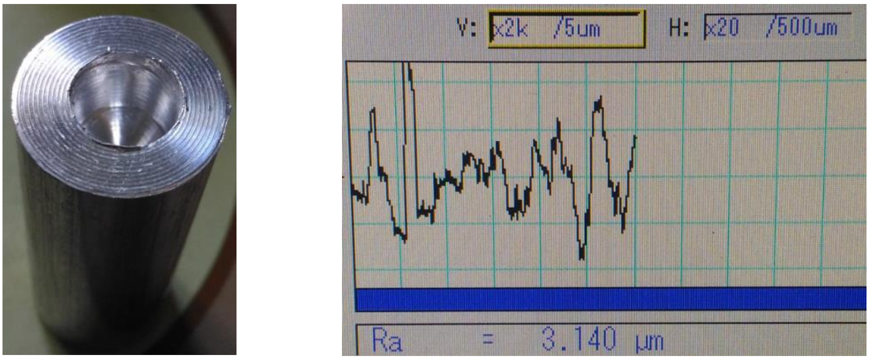


Figure 7. Analysis of finished product with 1.5 sec vibration frequency interval and surface roughness.

Summing up the above results, the mean borehole surface roughness of the processing object, under different vibration frequency intervals after four measurements, is shown in Table 1, where the bottom line represents the lowest in the evaluation standard. According to the table, the following results are concluded.

(1) Adding proper and continuous vibration frequency intervals, under the same processing conditions, could effectively improve the bore surface roughness and enhance the bore smoothness.
(2) Faster vibration frequency intervals do not necessarily present the best improvement. It is essential to match with certain processing conditions and parameter settings to find out the optimal vibration frequency interval.
(3) With slow vibration frequency intervals, the bore surface roughness, after certain area, would not be improved, but might cause opposite effect to worsen the bore roughness.
(4) When the vibration frequency exceeds certain area, the accuracy of the processed workpiece measured with the surface roughness measuring instrument would be largely reduced, possibly because the bore is no longer a proper circle, but appears ellipse or polygon.
(5) The maximum roughness (*Rmax*) is not necessary the best under good average roughness (*Ra*), possibly because of the vibration factor causing the obvious difference between the highest and the lowest vibration.

Figure 8 shows the surface roughness mean values versus vibration interval time. It indicates that roughness *Ra* with the vibration interval time 0.5 sec could improve the surface roughness 48.95% of the processing hole, comparing to it without vibration. At the same times, the best vibration interval timefor the smaller surface roughness valuesof *Ra*, *Ry* and *Rz* is 0.5sec, while *Rmax* is 0.2 sec.

Table 1. Surface roughness mean values.

Roughness	Non-vibration	Vibration interval time (sec)			
		0.2	0.5	1.0	1.5
Ra(μm)	3.379	1.992	<u>1.725</u>	2.170	2.830
Rmax(μm)	39.247	<u>25.798</u>	28.885	37.377	37.972
Ry(μm)	18.517	12.220	<u>11.443</u>	13.390	16.770
Rz(μm)	13.846	9.583	<u>8.254</u>	10.859	11.025

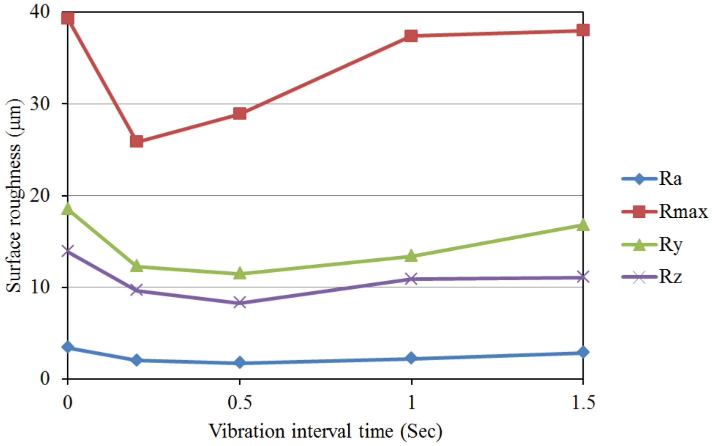


Figure 8. Schematic diagram ofsurface roughnessmean values versus vibration interval time.

5 Conclusion

Aiming at the homemade vibration platform, this study discusses the relationship between the vibration frequency interval and the processing borehole and tests the bore surface roughness of the processing borehole under different frequency. With statistical deduction, the following conclusions are summarized.

(1) Adding proper vibration factors, under the same processing conditions, could effectively improve the bore surface roughness and smoothness. *Ra* with the vibration interval time 0.5 sec, could improve the surface roughness 48.95% of the processing hole, comparing to it without vibration. Besides, the resonance phenomenon disappears at the feed to generate good effect.

(2) It is not necessary that the fast vibration frequency interval would generate better effect. However, adding slower vibration frequency intervals would affect the processing quality and stability, and even worse result than the processing without vibration.

(3) Under small mean roughness (*Ra*), the maximum roughness (*Rmax*) is not necessarily lower. In the experiment, the best vibration intervaltimeof *Ra*, *Ry* and *Rz* is 0.5sec, while *Rmax* is 0.2 sec.

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