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A comparative study on dry milling and little quantity lubricant milling based on vibration signals

Weiwu Zhong [a,*], Dongbiao Zhao [a], Xi Wang [b]

[a] College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, P.O. Box 245, 210016 Nanjing, Jiangsu, People's Republic of China
[b] School of Aeronautical and Manufacturing Engineering, Nanchang Hangkong University, 330063 Nanchang, Jiangxi, People's Republic of China

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ABSTRACT

Green manufacturing is the theme of manufacturing industry in the 21st century. In order to realize green manufacturing, it is critical to decrease the usage of cutting fluid in machining as much as possible. Presently, there are still a lot of difficulties in the adoption of dry cutting and MQL cutting for various reasons. This paper presents a new method called little quantity lubrication (LQL) in machining and a comparative study on dry milling and LQL milling based on vibration signals. The vibration signals were acquired from workpiece surface in peripheral milling and were analyzed in time domain, frequency domain and time–frequency domain. The results show that vibration signals can be significantly affected by cutting fluid in milling process. For the sake of reducing vibration and cutting fluid usage, process parameters should be considered while deciding whether or not and how to apply cutting fluid. This research gives a valuable insight in applying LQL in machining.

1. Introduction

In order to improve workpiece quality and prolong tool life, cutting fluid is introduced to cutting zone in metal cutting process. In general, cutting fluid used in metal machining plays an important role in promoting productive efficiency and improving process quality. An ample amount of cutting fluid used in machining can induce serious pollution of the environment in the whole manufacturing process. Oil mist, smoke, chemical particles and bacteria, which are caused by cutting fluid can easily pose a threat to the health of production workers [1,2]. Processes of steam cleaning and high-temperature treatment, which are used to remove the impurities on the workpiece surface, can generate the pollution of secondary effect [3]. Otherwise, from economic consideration, the cost of using cutting fluid is very expensive. From the viewpoint of environment protection and cost saving, it is critical to decrease the usage of cutting fluid in machining as much as possible in order to keep pace with the new trend of green manufacturing. The common approaches of green manufacturing relating to cutting fluid are dry cutting and MQL cutting.

Dry cutting and MQL cutting have been accepted as successful applications in machining because of their environmentally friendly characteristics. But they raise special demands to machine tools and cutting tools. Especially, there are still a lot of difficulties in the adoption of high-speed dry cutting because of the high cutting force and temperature in machining. Without cutting fluid, the function of cooling and lubrication will not exist, and this will cause severe friction and adhesion, reduce tool life and affect surface quality of workpiece.

As can be seen from Table 1, there is a large interval of lubricant flow rate between MQL and conventional wet lubrication (300–300 000 ml/h), which is rarely used. Such a method of little quantity lubrication is called LQL in this paper. In this work, LQL means that the flow rate of cutting fluid is 50–300 ml/min. Till now, far less attention has been paid to the application of LQL in machining. The consideration of introducing LQL in machining aims at achieving a good cooling and lubricating effect by using a small amount of cutting fluid. By this means, cutting process is in the best condition (not shorten tool life, not worsen the surface quality of workpiece), and the usage of cutting fluid can be reduced greatly to alleviate the negative effects of cutting fluid on human health and environment.

Many scholars have conducted research on the effect of lubricant on machining process. Wang and Chang [4] conducted an experimental study of surface roughness in slot-end milling. The results showed that dry-cut roughness was reduced by applying cutting fluid. Dhar et al. [5] investigated the effect of MQL in turning of AISI-1040 steel. This study compares the mechanical performance of MQL to completely dry lubrication for the turning of AISI-1040 steel based on experimental

* Corresponding author. Tel./fax: +86 0 25 84896370
E-mail addresses: zhongweiwu2008@yahoo.com.cn (W. Zhong), zdbme@nuaa.edu.cn (D. Zhao).

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Table 1
Flow rate of cutting fluid for different cutting styles.

Cutting style	Dry cutting	MQL cutting	Others	Wet cutting
Flow rate of cutting fluid	0	2–300 ml/h	–	≥ 300 l/h
Cutting fluid	–	Cutting oil	Cutting oil/emulsion	Cutting oil/emulsion

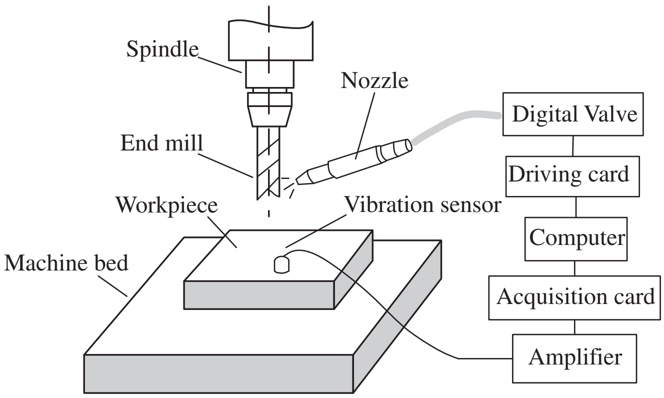

Fig. 1. Experimental setup.

measurement of cutting temperature, chip reduction coefficient, cutting forces, tool wears, surface finish and dimensional deviation. Jayal and Balaji [6] conducted an experimental study into the effects of different lubricant application methods on tool wear. Tsao [7] reported an experimental study of cutting fluid effect in milling aluminum alloy in comparing the milling force responses and flank wear under various cutting conditions. Aldo et al. [8] investigated tool wear mechanisms and tool life for an end milling operation under four different cooling and lubricant conditions. From these researches, it can be known that no attention has been paid to the effect of lubricant on cutting vibration.

Cutting vibration is mainly caused by the cutting forces and motions involved in cutting process. Yesilyurt [9] conducted a research of end mill breakage detection using mean frequency analysis of scalogram. His results showed that vibration signals in machining contained rich information of cutting state. Generally, cutting vibration is considered to be a very harmful phenomenon because it can lead to tool wear and worse surface quality of workpiece. In this paper, a comparison study of vibration signals on dry cutting and LQL cutting is conducted in time domain, frequency domain and time–frequency domain. The main purpose of this work is to reveal the effects of LQL on cutting process and provide an effective instruction to apply LQL to machining.

2. Experimental setup

Experimental setup is illustrated in Fig. 1. The experimental work was performed on Mikron UCP600 5-axis machining center. Up milling was performed in the experiment. The workpiece material used was aeronautic aluminum alloy 7050-T7451 in the form of a 150 mm × 150 mm × 45 mm block. A new diamond-coated flat end mill (20 mm diameter, 3-flute) was used in the tests. Axial depth of cut (a_a) in all the tests was fixed to 5 mm in order to limit the amount of testing times. Cutting fluid was a fully synthetic water soluble coolant in a volumetric concentration of 1:20, which was provided accurately by a digital valve to cutting zone. In order to obtain a higher injection speed of cutting fluid, the diameter of injection nozzle was only 1 mm. Piezoelectric accelerometer sensor was used to sample vibration signals. Vibration signals were sampled by data acquisition card Advantech PCI-1714U, the sampling frequency was 2 MHz. In order to assure the comparability among the tests, vibration signals were sampled at the same position that was approximately in the middle of every stroke.

Table 2
Experimental design.

Group no.	Test no.	n (rpm)	a_r (mm)	f (mm/tooth)
1	1	3000	0.5	0.05
	2	6000	0.5	0.05
	3	10000	0.5	0.05
	4	14000	0.5	0.05
	5	18000	0.5	0.05
2	6	3000	1.5	0.05
	7	6000	1.5	0.05
	8	10000	1.5	0.05
	9	14000	1.5	0.05
	10	18000	1.5	0.05
3	11	3000	3.0	0.05
	12	6000	3.0	0.05
	13	10000	3.0	0.05
	14	14000	3.0	0.05
	15	18000	3.0	0.05
4	16	18000	3.0	0.010
	17	18000	3.0	0.015
	18	18000	3.0	0.020
	19	18000	3.0	0.025
	20	18000	3.0	0.030

Experimental design is shown in Table 2. n is spindle speed at rpm, a_r is radial depth of cut, f is feed per tooth. There are 20 tests in the experiment, which are divided into four groups. Each of the 20 tests was conducted according to dry cutting (Cd), LQL cutting at 150 ml/min (C150) and LQL cutting at 300 ml/min (C300). Therefore, there are 60 tests in the experiment altogether.

3. Results and discussion

In metal machining process, vibration is caused by cyclic variations in the dynamic components of cutting force [10]. Different flow rates of cutting fluid may cause different friction characteristics of the secondary deformation zone between cutting tool and chip and the third deformation zone between cutting tool and workpiece. The change in the friction characteristics may result in the change of dynamic cutting force. Correspondingly, the features of random vibration of cutting tool and workpiece can be changed, which in turn affects the cutting vibration characteristics.

3.1. Time domain analysis

A typical time waveform of vibration signal is shown in Fig. 2. According to sampling rate and spindle speed, it can be calculated out that 8571 data are sampled in every cutting cycle. A cutting cycle is defined as the time required for the cutting edge to complete a 360° cut. Fig. 2 shows that the vibration signals are