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Sound Analysis in Drilling, Frequency and Time Domains

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Abstract

This paper proposes a guideline for interpreting frequency content and time history of sound measurements in metal drilling processes. Different dynamic phenomena are reflected in generated sound in cutting processes. The footprint of such phenomena including torsional, lateral regenerative chatter and whirling in sound measurement results are discussed. Different indexable insert drills, at several cutting conditions, are covered. The proposed analysis could be used for studying, online monitoring and controlling of drilling processes.

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1. Introduction

Considering recent advancements in sensor technologies, digital signal processing and rapid adaptation of digitalization and automation in manufacturing, online monitoring of metal cutting processes is going to be more prevalent. Drilling as an important operation in machining will not be an exception and therefore it deserves detailed studies tailored for different types of drills and different drilling processes.

Almost a third of machining time is spent on making holes [1]. Drilling as the main method to make holes can be categorized into deep-hole and short-hole drilling. The main types of drills to make short holes are exchangeable tip, solid carbide and indexable inserts drills. A more generic classification is to divide drills into symmetric and asymmetric tools. In this paper, a symmetric drill is a drill that is symmetric around its rotational axis. The importance of this classification will be clarified later in this paper. While exchangeable and solid carbide drills are usually symmetric, indexable insert drills are dominated by asymmetric designs.

Regardless of its type, a drill mounted in a machine tool can be represented as a cantilever beam which is loaded by a cutting torque around the rotational axis and a thrust force along this axis. In Fig. 1, a schematic model of a typical drill-body is shown.

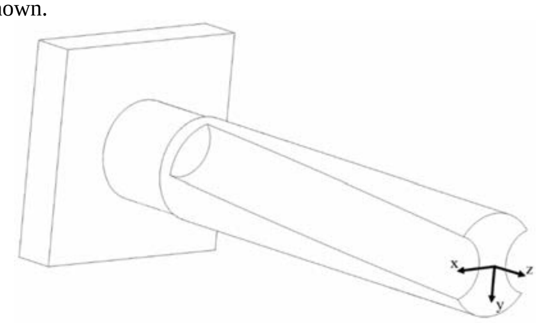

Fig. 1. A schematic model for a typical drill-body

Cutting forces cause deflections of the drill-body. The cutting torque twists the drill and the thrust force compresses it. Because of the helical structure of the drill and the warpage of the noncircular cross section, axial and torsional deflections of a typical drill-body are coupled [1-3]. This means that the cutting torque affects the length of the drill and the thrust force twists the drill [2, 3]. If the cutting tip of the tool is not symmetric around rotational axis, it can lead to unbalanced

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forces on the plane perpendicular to drill axis, x, y-plane, which are called lateral forces in this paper. Furthermore, an asymmetric geometry can cause coupling between torsional and bending deflections [2]. Therefore, even if the lateral forces are balanced, an asymmetric drill can bend because of the cutting torque. Bending of the tool either due to unbalanced lateral forces or a torsional-flexural coupling can deteriorate the dimensional accuracy of the hole.

In addition to static and quasi-static loads, drills can experience dynamic loads which cause vibrations. Vibrations in metal cutting, including drilling, can be categorized into free, forced and self-excited vibrations [4]. In practice, a drilling process can show a combination of all three types. However, depending on the drill, cutting conditions, the workpiece material, the machine-tool and the holder, one of the mentioned types might be dominant.

Surveying the literature shows that most of the effort in drilling vibrations research are dedicated to modelling of torsional-axial chatter [5-12], lateral chatter [9-14] and whirling vibrations [15-18]. Some of recent studies on vibrations in drilling includes work done by Rouckema and Altintas [9, 10], Ahmadi et al. [11, 19] and Parsian et al. [6-8].

Modelling of the vibrations is not only a prerequisite for a better tool design but also helps a better interpretation of the measured vibrations. Vice versa, a good measuring method is needed to verify the models and to help monitoring and diagnosis. Some previous work on monitoring of vibrations in metal cutting is reported by Tarng and Li [20, 21], Dimla Sr. and Lister [22], Kakinuma et al. [23].

Although measurements of structural vibrations give very useful information about metal cutting processes, these measurements are very challenging in case of drilling operations. Unlike turning and milling, a drilling process occurs inside a hole where it is difficult to observe or measure the vibrations. One way to capture a part of the dynamic behaviour of drilling without facing the mentioned difficulty is to measure the cutting sound.

Vibrations of tool-machine-workpiece system induce pressure waves into the adjacent air which can be measured by a microphone close to the machine tool. This is a compromise because many useful details about the vibrational level cannot be extracted from sound measurement and still it can provide useful insight into the process. Furthermore, setups for measuring sound in metal cutting operations are among the cheapest and easiest measurement setups and therefore it is a suitable method in many workshops for monitoring purposes.

Although many papers have covered the topic of vibration in drilling, the authors believe that there is a gap in researches dedicated to sound analysis of drilling. Considering the mentioned benefits of the sound measurement analysis, and the fact that most of the researches are focused on the modelling rather than measuring, this paper aims to be a guideline on how to use and interpret the measured sound of a typical drilling process.

2. Processing of measured sound signal

This section discusses how to process measured sound from a drilling process in an appropriate way. Discrete signal processing (DSP) techniques are usually used to treat measured sound. According to sampling theorem, in order to avoid distortion, a signal must be sampled at a rate at least as big as twice of its highest frequency content [24]. Considering both psychoacoustics aspect and typical drill design, 20 kHz can be considered as the maximum frequency of interest in the signal. Therefore, a sampling frequency of more than 40 kHz is suggested. A low pass filter is applied to prevent aliasing.

Welch’s method [25] is suggested [26] to estimate power spectral density, PSD, of the signal. In Welch’s method, the time history signal is divided into several segments [25]. The modified periodogram of these segments are calculated and are then averaged to estimate spectra of the signal [25]. To reduce the leakage, appropriate time window must be used. Flattop window is suggested to have a better estimation of the amplitude of periodic components in the signal [26]. The square root of the area under the obtained power spectral density represents RMS values [26].

The distance between frequency points in discrete Fourier transform, Δf , decreases by increasing the length of the segments as follows [26]:

$$\Delta f = \frac{1}{T} \tag{1}$$

T is the time length of the data block. However, doing these reduces the number of segments, hence increases the random error [26].

The sound measurements in this paper are done using a microphone mounted at about 20 cm from the CNC door. The signals are sampled at a rate of 83kHz. The workpiece material is steel, SS 2541. The machine tool is a Mori Seiki NH 8000 DCG.

3. Contents of drilling sound

A typical result of a sound measurement in drilling is shown in Fig. 2. The key for appropriate interpretation of such a measurement is to know what to expect from the measured data. Most common vibration mechanisms in drilling which are mentioned in the literature include torsional chatter [5-12], lateral chatter [9-14] and low frequency whirling [15-18]. Adding to these, chip jamming and the tool damage can be reflected in the sound measurement contents.

In general, a sound signal captured during drilling process can be a combination of:

1- Torsional-axial chatter vibrations
2- Lateral chatter vibrations
3- Noise generated by coolant flow, chip evacuation, chip jamming.
4- Low frequency whirling vibrations
5- Background noise in the workshop which does not correlate to the dynamic behaviour of the drilling process
6- Tonal components generated by the spindle and gearboxes.
7- Noise generated by various pumps used in hydraulic systems and lubrication systems of the machine.

Among the above contents, the first four are interesting for drilling study purposes. In this section, these contents are