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Study based on sound monitoring as a means for superficial quality control in intermittent turning of magnesium workpieces

Diego Carou[a,b], Eva Mª Rubio[a,*], Carlos Henrique Lauro[b], Lincoln Cardoso Brandão[c], J. Paulo Davim[b]

[a]*Dept. of Manufacturing Engineering, National University of Distance Education (UNED), C/ Juan del Rosal, 12, Madrid E28040, Spain*
[b]*Dept. of Mechanical Engineering, University of Aveiro, Campus Santiago, Aveiro 3810-193, Portugal.*
[c]*Dept. of Mechanical Engineering, Federal University of São João del Rei, Praça Frei Orlando 170, São João del Rei 36307-352, Brazil*

* Corresponding author. Tel.: +34 91 398 82 26; fax:+34 91 398 60 46. *E-mail address:* erubio@ind.uned.es

Abstract

The usage of the monitoring processes can improve the efficiency in the machining operations, allowing the reduction of costs and waste. Processes that monitor the acoustic emissions, cutting forces or vibrations present great results, however, they are very expensive. In this paper, it was studied a low cost alternative to monitor the turning of UNS M11917 magnesium workpieces. The experiments were defined employing different machining conditions: cutting speed and feed rate, and various workpiece geometries to analyze the sound signal in the intermittent turning process. Four response variables were analyzed: two related to the surface roughness and the other two related to the sound signal. In spite of ambient noises, the method proved to be useful to predict the surface quality of the machined surface based on the maximum peak-to-peak amplitude of the sound signal.

Keywords: Dry Machining; Intermittent Turning; Machining Monitoring; Magnesium Alloy; Sound Analysis

1. Introduction

Machining processes are extensively used in a wide range of industries for the production of components [1]. With machining operations it is possible to obtain great accuracy and good surface quality when ensuring the perfect order of the set up (machine, tool, and cooling system). However, it is difficult to guarantee the optimal performance of the process because of the complexity of the machining processes. For instance, as the wear of the cutting tool is increased, it is more difficult to achieve good surface quality and dimensional tolerances [2].

In the last decades, attention has been put on the monitoring of the machining process instead of analyzing its final outcomes. The monitoring of the processes can be based on data estimated from plant data (mechanistic models), or it could be based on plant data (data-driven or empirical models) [3]. The most effective techniques in practice are those based on models constructed almost entirely from process data [4].

Monitoring of machining operations has attracted the attention of researchers and review studies such as the ones presented Teti et al. [5] and Lauro et al. [6] represent good overviews of the current state of the methods and strategies used for the monitoring of machining operations. Special attention was given to Tool Condition Monitoring (TCM). For instance, in 1995, a detailed review study was presented by Byrne et al. [7]. Databases of references were also presented by Teti [8] and Teti et al. [9] reviewing and classifying the main studies on TCM from 1960 to 2006. On-line TCM offers great accuracy and it is a useful tool for improving the machining processes. However, the use of TCM is sometimes unmotivated because of its high cost, for instance, when using methods based on the analysis of forces [10].

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The interest in on-line monitoring is encouraged by a competitive economy that puts in first line automation and flexible manufacturing [11]. Based on this approach, industries can improve the productivity of their processes and the quality of their manufactured components. An option for controlling machining processes is the use of signal monitoring that allows the control of parameters such as cutting forces, noise, temperature and vibrations [6], and chip morphology [12].

According to Neto et al. [13], a better understanding of the influence of the machining parameters on the outputs can help the operators define an ideal condition between design and productivity. Authors compared the cutting forces in the milling of complex shapes with the surface roughness. However, the on-line real-time monitoring methods have some drawbacks that must be considered. For instance, some signals may be redundant; measurement errors are not easy to be avoided resulting in inaccurate prediction; and the cost for measuring is relatively high [11]. Sometimes, the acquired signals are altered by the frequency range making the results of the monitoring process not useful. An approach to avoid these problems is the use of non-periodic excitation and statistical signal processing techniques that requires selecting adequately the frequency range, number of test averages and windowing procedure [14].

Cutting processes are assumed to be nonlinear and non-stationary, so, the selection of an adequate processing technique is of importance in monitoring [15]. Some of the main techniques used for signal processing were conveniently reviewed by Lauro et al. [6] including: Time domain analysis (once per revolution sampling, Poincarè sections), Fourier transform, Wavelet transform, Hilbert and Hilbert–Huang Transform and other methods.

The sound produced in the cutting process contains important information about it. So, it can be used to identify table movements, tool changes and machining with various cutting tools; failures of the machines or tools; and occurrences of abnormal machining conditions [16]. For instance, the chip formation process can be suitable in TCM because of the emission of acoustic energy at high frequencies. The low frequency audio signal can be detected by means of a microphone [14].

The use of microphones is suitable for chatter detection in milling, being their sensitivity to chatter onset comparable to that of expensive sensors (accelerometers, displacement probes and plate dynamometers). However, for successful application, environmental noise should be suppressed. Besides, there are some limitations to take into account such as directional considerations, low-frequency response and environmental sensitivity [17]. Furthermore, the microphone is a low cost solution to detecting chatter [14].

Magnesium is a material that is extensively used in sectors such as aeronautics, automotive, medical and sports [18] because, among others, it provides low density and competitive specific properties [19]. Magnesium has good machinability though there are drawbacks associated to the machining process, such as the ignition risk that should be taken into account [20]. An experimental study on intermittent turning of magnesium alloys for repair and maintenance operations was presented by Carou et al. [21]. Authors analyzed the influence of the machining conditions (cutting speed, depth of cut and feed rate) using dry machining recognizing an important influence of the feed rate on the surface roughness. Moreover, the selection of reduced cutting speeds avoided the appearance of fire during machining.

The present study evaluates the use of sound monitoring in the intermittent turning of UNS M11917 magnesium for controlling the surface quality of the process.

2. Experimental studies on sound monitoring

Sound monitoring is a control technique that has been successfully used in several machining processes [5,6]. Particularly, sound monitoring has been used in turning. For instance, Lu & Kannatey-Asibu [22] monitored the forces, sound signals and vibrations in the turning of AISI 8620 steel. The results agree qualitatively with the frequency characteristics of experimental data obtained with sharp and worn tools. So, for signals above 0.5 kHz, similar peaks were obtained for both the sound and vibration signals in the feed and cutting directions. Tekıner and Yeşılyurt [23] used the sound monitoring in the turning of AISI 304 stainless steel. They measured and recorded pressure levels of process sound using a microphone identifying that the cutting sound pressure levels have decreased parallel to positive results occurred in chip removal. They affirmed also that cutting sound pressure level is an available method to develop an alarming system. Salgado and Alonso [24] analyzed the turning of AISI 1040 steel using sound monitoring. Authors stated that the sound signal emitted during turning and the feed motor current has an acceptable cost-performance ratio for its industrial application for TCM. Maia et al. [25] monitored the acoustic emission signal to correlate it to tool wear and wear mechanisms using the Power Spectral Density and auto-covariance in the turning hardened AISI 4340 steel. Haili et al. [26] analyzed the tool breakage in the turning of 45 carbon steel using sound signals and motor power. Because of the difficulty of distinguishing various acoustic emission signals, authors used time–frequency analysis to extract features from the signals.

3. Materials and experimental procedures

To evaluate the use of sound signals for monitoring the surface roughness in machining, workpieces of UNS M11917 magnesium alloy were machined in the Kingsbury^{TM} MHP 50 CNC lathe (spindle power of 18 kW and maximum spindle speed of 4500 rpm). The selection of an intermittent machining process was done to evaluate the influence of workpiece discontinuities on the acquired signals. The study of interrupted surfaces is important because nowadays pieces have complex geometries including holes, lubrication channels, splines and key slots [27,28]. Thus, it is intended to evaluate if the discontinuities have influence on the sound signals because of the mechanical impacts between the tool and workpiece. The UNS M11917 magnesium alloy was chosen due to their good machinability in order to avoid sensitive variations during the machining. The workpieces