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Use of the phenomenon of acoustic emission for real-time monitoring of milling processes

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ABSTRACT

With the advent of new manufacturing philosophies based on zero mistakes and the need to produce high precision elements for the aeronautic industry, there is an increasing need of real time monitoring of high precission machining processes in order to assure that every component will successfully perform its duty without the need to perform any testing (destructive or non-destructive), which would imply an increased manufacturing time and the loss of valuable components.

Nowadays, most processes are thoroughly studied to confirm its suitability by using dynamometers or surface acoustic emission sensors coupled with the known mathematical models for chip generation, but the apparition of robust microphones capable to function in harsh conditions and MEMS microphones with a wide frequency range open new possibilities of non-intrusive monitoring based on contactless sensors.

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1. INTRODUCTION

The addition of acoustic emission sensors in the field of precision machining [1, 2] can potentially be used to display of the different machining parameters in real-time without damaging the sensors with metal chips or cutting fluid, and the use of microphones to detect the acoustic emission generated by metal being cut could provide a steady flow of information of each chip generated, but of course, even with these advantages there are still many challenges that need to be addressed before the actual implementation of the proposed system as a proper aid in process design and monitoring:

- The machining of new titanium alloys adds a number of problems while machining, like the apparition of chatter because of its low Young module, long chips during continuous drilling, irregular chips during milling or addition of metal to the cutting tool, which hinders the use of acoustic emission sensors [3].
- The high cost of the pieces that need continuous monitoring also conditions the methodology that is going to be used when manufacturing them, favoring more traditional methods over modern ones whose characteristics are not still fully understood [1].
- Whenever a workpiece is being machined, it is not trivial to relate the already noisy signal of an acoustic emission sensor with an imperfection of any source during the process [2].
- The use of complex toolpaths decreases the accuracy of the data provided by acoustic sensors.

2. ACOUSTIC EMISSION

Acoustic emission (AE) has attained a notable focus in the engineering community in the recent years, both in contact sensors [1, 2] and non-contact ones [4] due to their increased sensibility against their main alternatives such as the traditional encoders, load cells and laser interferometers [4] because of the fact that it represents an inexpensive and non-intrusive alternative to the more traditional methods.

Acoustic Emission refers to to the mechanical waves generated by the plastic (irreversible) changes in solid bodies during the application of stress that can produce friction, cracks, deformations and movement of dislocations among others [5], and that phenomena can be produced not only in the workpiece that is losing material, but also in the interactions between the resultant chip and the cutting tool.

Besides the clear use of the AE phenomena in the machining field, it has also been used in detecting weak points in metallic structures such as piping [6], aircraft [7] and windmills [8].

Table 1: Data acquisition parameters.

Parameter	NI 6251	NI 9234	
Sampling speed	50	50	kHz
Resolution	16	24	Bits
Range	±5	±5	V
Crosstalking	-75	-110	dB
DNR	98.1	97	dB

Table 2: Cutting conditions of machining tests.

Axial depth of cut	a_p [mm]	2
Radial depth of the cut	a_e [mm]	2
Feed per tooth	f_z [mm]	0.04
Spindle speed	n [rpm]	1200
Tool flute number	N [-]	3
Tool diameter	D [mm]	12
Tool helix angle	λ_s [°]	30

AE is also intended to be used in operations beyond milling as presented in this paper, like drilling, boring or even with the use of different machinery such as lathes since all those methods can benefit from tool monitoring [9]. That being said, one of the most important factors that can potentially hinder the measurements is the background noise from other machines, operators, electric motors, etc; so new approaches were used in pursue of a flexible method that could work under different operating conditions with high accuracy. Among such efforts, using artificial intelligence neural networks with fuzzy logic [10–12], or radial basis functions [13] have proven to be effective after a reasonable amount cycles, but they are not suitable in any case for small batch manufacturing.

3. EXPERIMENTAL SETUP

The main objective of this work is to stablish the relationship between the signals acquired by a commercial dynamometer and a microphone. The dynamometer used is a Kistler 9257B, which was connected to a Kistler 5070 amplifier to both amplify the incoming signal and filter the high-frequency noise embedded in it, with the resulting signal being sent to a NI 6251 DAQ board (Table 1). The main sensor for the microphone system is a commercial SPU0410LR5H-QB microphone that is attached to a specially made board that will perform the roles of amplifier, energy source and noise removal via electrolytic capacitors, with the signal being acquired by a NI 9234 DAQ board (Table1) (Figure 1).

All the machining operations were performed in a DMG 1035 three-axis machining center, and an end milling tool was used. Table 1 shows a summary of the cutting conditions used to machine a piece of 7075 aluminum along its shorter side (60 mm), with the microphone standing perpendicular to the center of its side and at a distance of 50 millimeters.

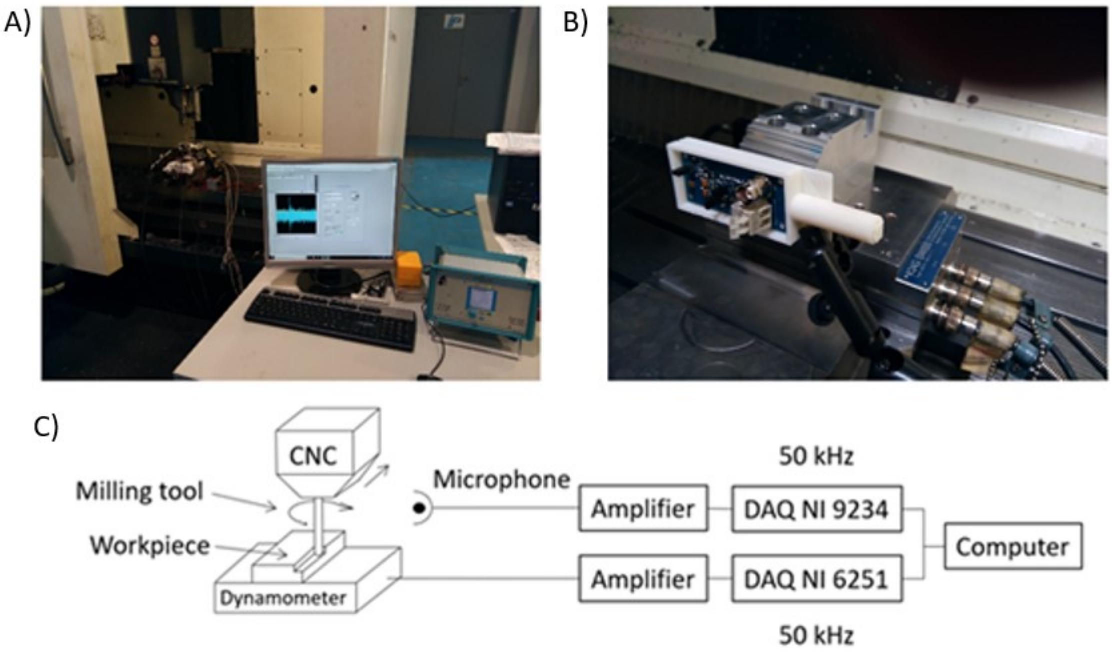

Figure 1: Setup of the experiments (A), close-up of the microphone (B) and schematic of the elements of the experiment (C).

4. RESULTS

Cutting tests were performed under a wide range of cutting conditions, and the data acquired during the experiment with the conditions of Table 2 provided the most insightful results, showing three clearly differentiated parts on the resulting signal along the tool path (Figure 2).

During the first section, the machining tool is approaching to the workpiece, so no material is being removed and the dynamometer signal is completely flat except for the intrinsic electric noise of the device. In contrast, the data acquired from the microphone is also steady, but in this case the electric noise is not the main factor in the signal, since the microphone is also acquiring the noise of the actuators of the machine, its electric drives and the background noise of the room.

Once the cutting tool reaches the workpiece, the machining process starts the immersion increasing phase (section 2), the tool needs to reach the maximum depth of cut and during that process the amount of metal removed will be increased steadily with a duration depending on the cutting feed (fz) and the helix angle of the tool. During this stage, the values of the dynamometer displays a steady increase in the cutting force values. Regarding the microphone, the first chips removed from the workpiece are difficult to discern just by analyzing the raw data of the experiment because of the presence of background noise.

Finally, at the third section of the studied signal, the commanded machining conditions have been reached. In this case, the dynamometer displays a clear and regular signal, and the microphone also provides a signal with roughly the same amount of information once it has been filtered (Figure 2) in order to reduce the high-frequency noise embedded in the signal.

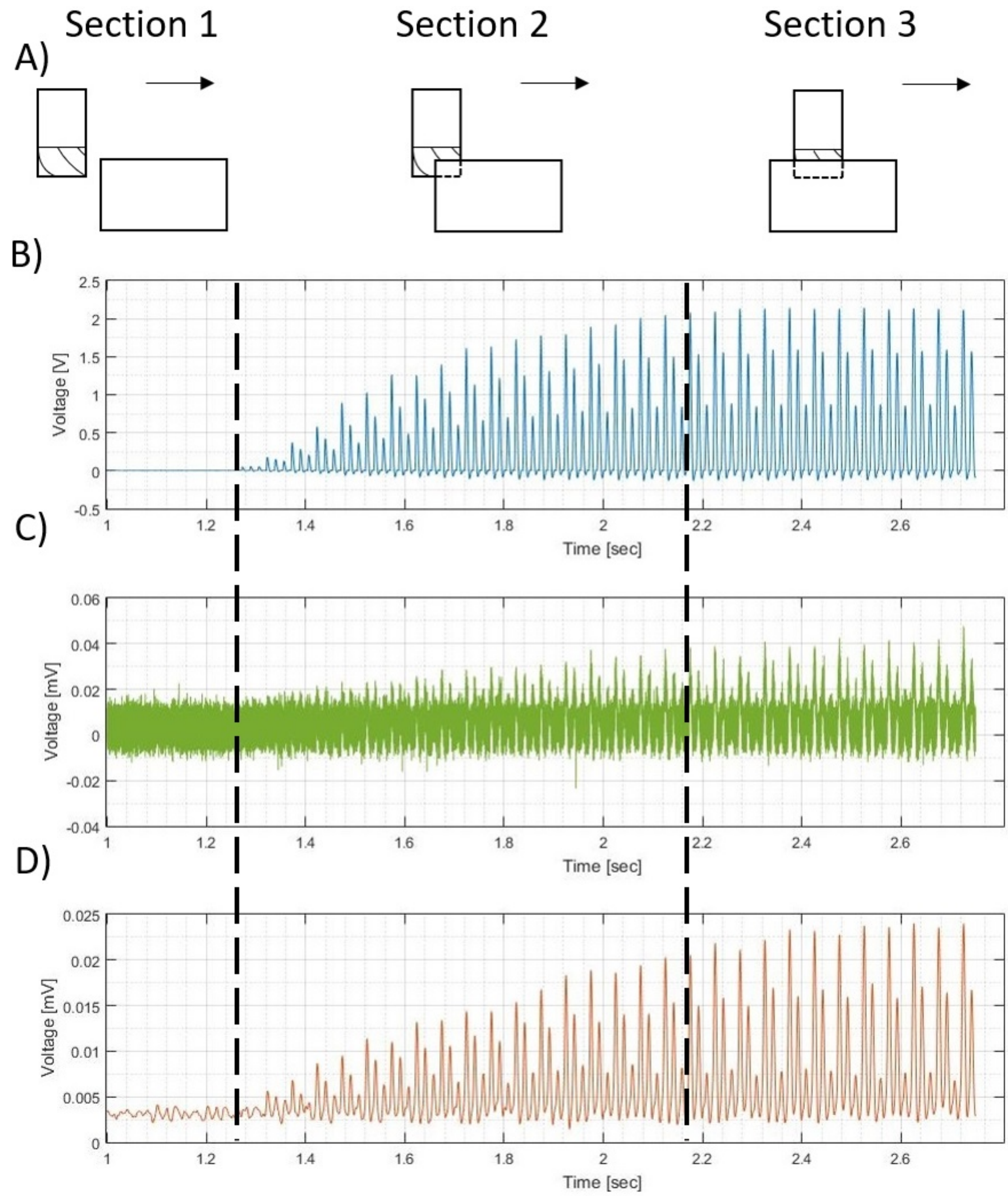

Figure 2: Relative position of the tool regarding the workpiece in each section (A), signal generated by the dynamometer (B), the microphone (C) and the filtered signal of the microphone (D) during the machining process.

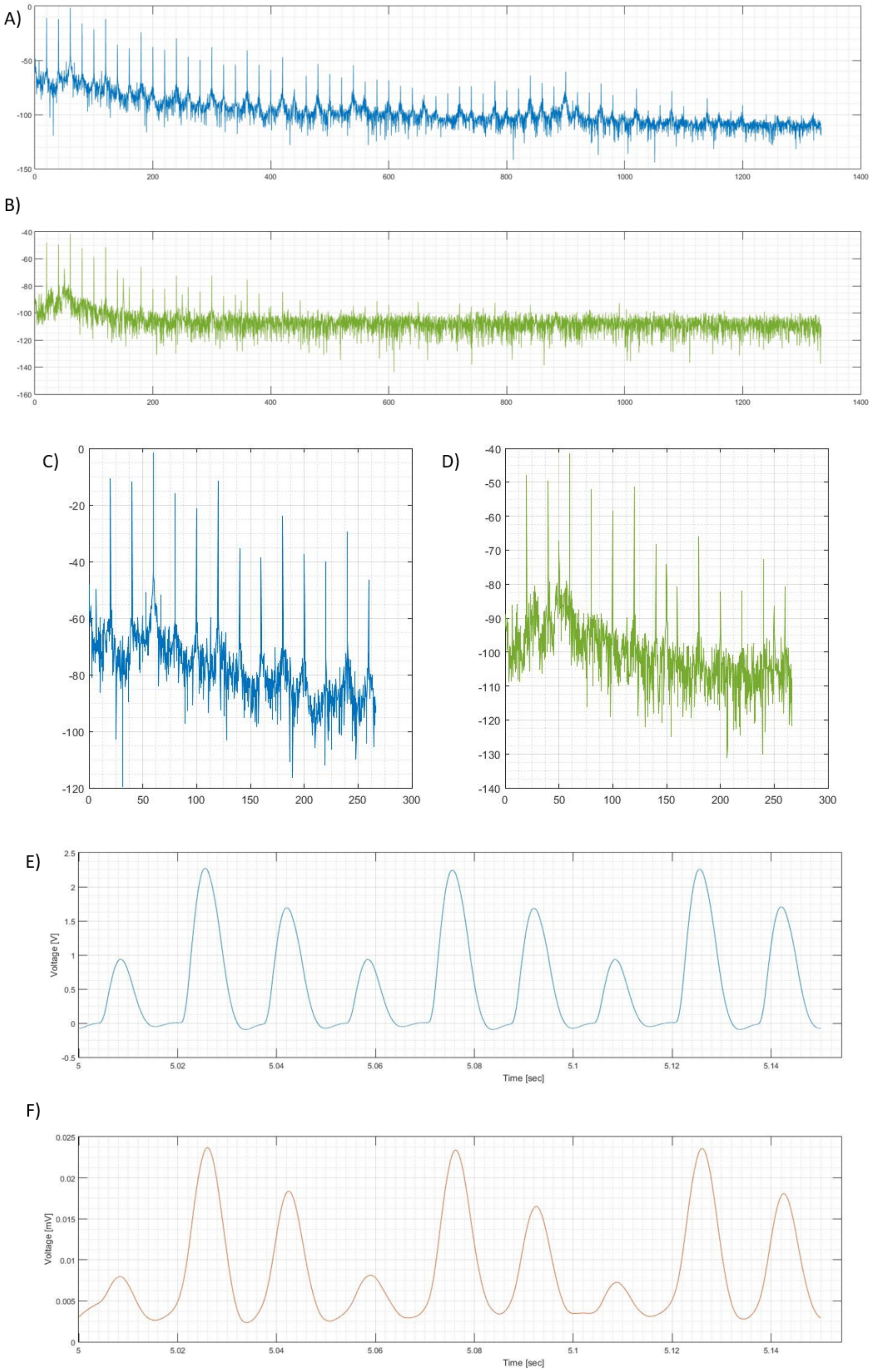

Figure 3: FFT of the dynamometer (A,C) and microphone (B,D) during stable machining conditions, close-up of the signal of the diamometer in stable conditions (E) and close up of the filtered signal of the microphone during stable conditions (F).

5. FILTERING OF THE ACOUSTIC DATA

A close analysis of the Fast Fourier Transform (FFT) of the signals during stable machining conditions (Figure 3C and Figure 3D) reveals that both signals have energy peaks at the fundamental frequency of the spindle (20 Hz) and its harmonics. Additionally, the FFT of the microphone also shows a fundamental frequency at 50Hz plus its harmonics due to the presence of electrical devices in the vicinity.

Analyzing the figures 3A and 3B, the dynamometer has FFT peaks that decrease steadily until their disappearance at around 1 kHz, while the microphone has values that disappear much earlier and whose difference in value compared to the noise is much lower, so it was decided to filter the acoustic signal with a low-pass filter with a cutting frequency at 150 Hz.

In Figures 3E and 3F the dynamometer and microphone signals are shown . Firstly, it is necessary to notice the decreasing values of both force in the dynamometer and acoustic emission in the microphone present cyclically in each full revolution of the cutting tool due to tool runout [14], although in a slightly less uniform way in the microphone because of the background noise present during the measurements and because of how the lowest peak was originally embedded within the original noise signal.

Regarding the clear difference between the signals in their valleys, it can be noted that not only there is a clear difference between both sensors, but the microphone also adds a seemingly random irregularity potentially attributed to the background noise, but even if that was not a factor, those valleys are related to the impulse response of each sensor, the associated hardware for signal processing and the data beyond 150 Hz that was filtered in the case of the microphone.

It is also worth mentioning that after the digital filtering of the acoustic data, the resulting signal is in phase with the force signal of the dynamometer, with small phase variations from peak to peak that can amount up to ±5 degrees.

6. CONCLUSIONS

The addition of microphones to milling processes is close to detect the contact tool-workpiece and to evaluate the grade of immersion of the tool without contact with the workpiece. Once permanent cutting conditions have been achieved, each cut by each individual tooth can be acquired and plotted with accuracy compared to the data provided by a dynamometer, which is used as the reference since it is the current most common approach when measuring machining conditions [15].

These preliminary results encourage further testing with the aim of finding the limits of this technology in process monitoring applied to the machining field, since a proper monitoring of is ought to reduce the number of inadequate components by detecting the potential tool breakage or disruptions during the process like chattering; and in the recent years, there has been an effort to introduce new methods of monitoring based on acoustic emission to detect factors such as toolwear/malfunction [16] or chatter [17] before a destructive event in the tool/spindle or damage in the workpiece surface happens.

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