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ANALYSIS OF ROUGHNESS, FORCE AND VIBRATION SIGNALS IN BALL-END MILLING PROCESSES

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ABSTRACT
In the present paper, roughness, force and vibration signals from ball-end milling processes are analysed. From the roughness signal actual feed value was obtained as expected. From the force and vibration signals both the frequencies of harmonics corresponding to rotation speed of the tool and impacts of teeth were detected.
Keywords: Ball-end milling, Roughness, Force, Vibration, Signals.

1 INTRODUCTION
In this work previous considerations in order to obtain tools that allow predicting surface roughness from vibration signal in machining processes are presented. For this reason, research started with data from milling operations as a wide known process, specifically ball-end milling. Several authors have studied surface in ball-end milling processes, by means of modeling as a function of process kinematics and geometry, for example Antoniadis et al. [1] and Buj et al. [2]. Correlation between roughness and vibration signals has been studied in the literature mainly in turning processes [3,4]. In milling processes, for example, Mendes de Aguiar et al. studied relationship between roughness, force and vibration in order to achieve low roughness and long tool life with slender tools [5]. In the present paper, roughness, force and vibration signals in ball-end milling processes were analyzed, as a first step towards correlation between roughness and vibration signals. New knowledge in this field can provide important improvements to other machining processes, such as honing, used in reciprocating internal combustion engines, in relation to the capacity of the cylinder to retain oil on vertical surfaces in order to decrease mechanical friction losses between piston and rings and cylinder surface [6].

2 MATERIALS AND METHODS

2.1 Experimental tests
Experimental tests were carried out in a vertical Mori-Seiki Dura machining center. Following cutting conditions were employed: cutting speed = 180 $m \cdot min^{-1}$ (9550 min^{-1}), feed = 0.4 $mm \cdot tooth^{-1}$, axial depth of cut = 0.15 mm, radial depth of cut = 0.4 mm. A ball-end milling tool of 6 mm diameter having 2 teeth was used to machine a hardened steel WNr. 1.2344 block. Parallel passes of 66 mm length were performed.

2.2 Measuring instrumentation

Data acquisition system consisted of a Kistler 9257B dynamometric plate for measuring forces ad moments in X,Y and Z directions, and two accelerometers CTC model AC102-1A for obtaining acceleration signal along X and Y axes. Z is tool axis and axial depth of cut direction; Y is feed direction; and X is radial depth of cut direction. Roughness was measured with a Taylor Hobson Talysurf Series 2, with µltra software (v. 4.6.8). Roughness was measured both in the longitudinal and in the transversal direction to machining marks.

3 RESULTS

First, acquired force, momentum and vibration signals are presented, as an example, for one experimental test. Next, feed employed was calculated from average value of peaks and valleys width in the roughness signal. Then, Fourier transform was applied to both force and vibration signal, and main components of the signal were obtained.

3.1 Roughness

As an example, in Figure 1 roughness signal for experiment with feed = 0.4 mm·tooth^{-1} and radial depth of cut = 0.4 mm is presented. Sample distance ratio is 4000 samples·mm^{-1}.

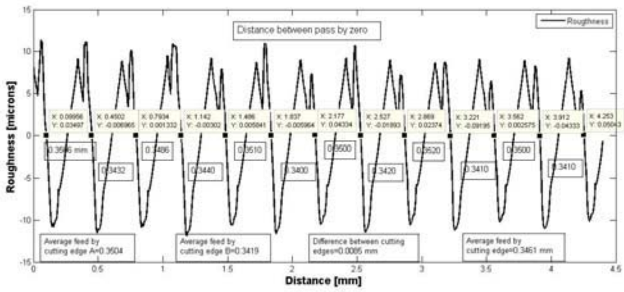

Figure 1. Roughness signal

In the figure it is observed that, although theoretical feed f is 0.4 mm·tooth^{-1}, actual feed value is 0.3461 mm·tooth^{-1}.

3.2 Force, momentum and acceleration

Forces measured in three directions X, Y and Z are shown in Figure 2.

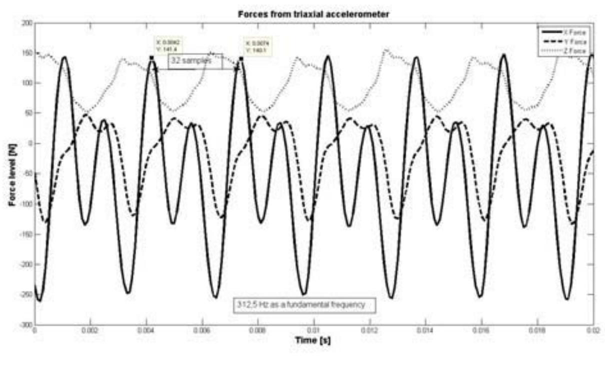

Figure 2. Forces in three directions

Amplitude of X forces is greater than amplitude of Y, and this exceeds amplitude of Z forces.

Momentums in the three directions are shown in Figure 3.

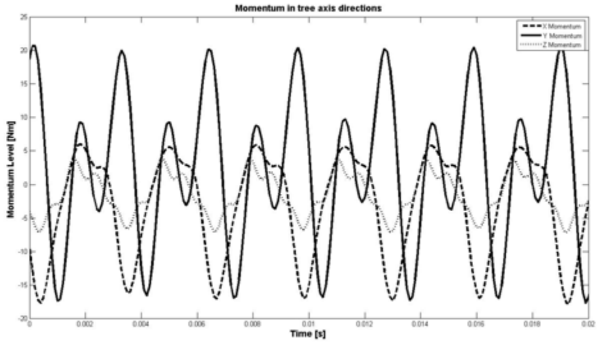

Figure 3. Momentums in three directions

Amplitude of Y momentum is much higher than that of X and Z momentum.

Figure 4 depicts vibration level in two directions.

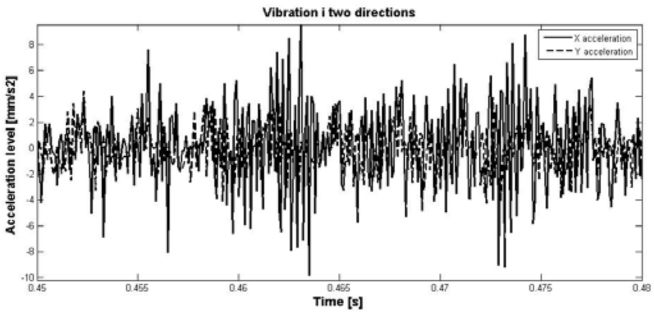

Figure 4. Vibration level in two directions

Amplitude of X acceleration is higher than amplitude of Y acceleration.

Sampling frequency for vibration, force and momentum signals was 10.000 samples$\cdot s^{-1}$.

3.2 Fourier analysis

In order to contrast information contained in spectra, fft fast fourier transform from roughness, force, and vibration signals was obtained. Most significant results are explained next. Frequencies of the signal force in X-direction are presented in Figure 5, while frequencies of vibration in longitudinal and transversal directions are shown in Figure 6. From those figures, three kinds of data results were extracted:

a) Fundamental frequency of 320 Hz is related to cutting edge impacts, while harmonics have frequencies 638 Hz and 958 Hz respectively (Figure 5);
b) Other low frequency components with lower amplitude level can be appreciated in the same figure (Figure 5): 162 Hz as fundamental, 480 and 800 Hz as harmonics corresponding to rotation speed of the milling tool, and it is caused by small geometrical and positional differences between the two tool edges; and finally,
c) High frequency components from the vibration signals in the X direction in the high frequency band can be extracted, related to a different kind of information, like mechanical resonances of the machine parts (Figure 6).

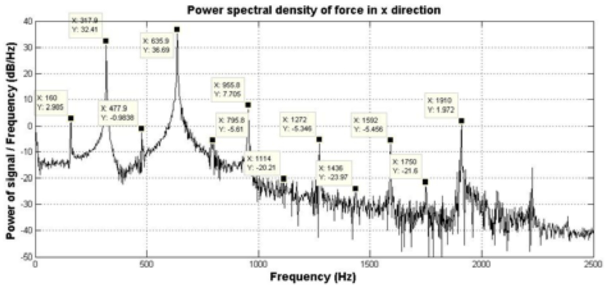

Figure 5. Fourier spectrum of force in the X direction

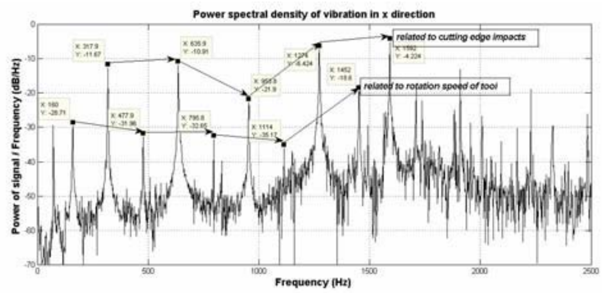

Figure 6. Fourier spectrum of vibration in the X direction

It is important to remark that the information contained at low frequencies of X-force signal and of X-vibration signal are redundant. Therefore, in this case it is sufficient to consider vibration signal only.

4 CONCLUSIONS

In a ball-end milling test, roughness signal allowed obtaining actual feed value employed. Application of Fourier transform to force and vibration signals provided information about number of cutting edges and rotation speed of the milling tool.

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