MULTI-PARAMETRICAL MONITORING OF GRINDING PROCESS FOR INCREASE PROCESS QUALITY

Abalaru A.[1], Stanciu D.[1], Cioboata D.[1], Savu L., Marin C.[2]

[1] National Institute for Mechatronics and Measurement Techniques, 6-8 Pantelimon Road, 2nd District, 021631, Bucharest, ROMANIA, E-mail: incdmtm@incdmtm.ro)
[2]Valahia University of Târgoviste, Faculty of Materials Engineering, Mechatronics and Rototics, Bd. Unirii, no. 18 - 24, 130082, Targoviste, Romania, E-mail: marin_cor@yahoo.com

Abstract: *During the grinding process are generated a lot of vibro-acoustical emissions. The monitoring of these emissions is necessary for the optimization, control and keeping of the process in allowable limits. A method and an apparatus were developed for monitoring of the grinding process components: acoustic emission generated during cutting process by the contact abrasive wheel – part; vibrations generated in the abrasive wheel shaft by the unbalancing of the abrasive wheel; geometry of the part processed; geometry of the abrasive wheel.*

Keywords: *process, control, grinding, monitoring, acoustic emission, vibration, dimensional control*

1. INTRODUCTION

The grinding is a final machining process, short, whose output is the processed part. At the end of the grinding process, the finished part must have high accuracy for three base features: dimension, shape and roughness. A stable grinding process is assured by integration of feedback loop, which measures continuum the part diameter what is processed, controls the changes of working cycle parameters and stops the process when the part has the dimension predicted. The monitoring of a single parameter is incomplete, because neglects the influence of the other parameters.

The increase of part quality and productive rate requires multi-parametrical monitoring of the main components of grinding process: the part and the abrasive disc.

In this paper is presented a solution for multi-parametrical monitoring of grinding process, following both the part dimension evolution and the level emissions generated by abrasive disc during the process (noise, vibrations).

2. MONITORING SYSTEM

We have designed and realised a monitoring system, composed of four modules, selectable on the monitor of the industrial computer, SIMATIC type. The four parameters followed by modules are: part diameter, level of acoustic emissions, level of vibrations and the shape of the abrasive disc. The monitoring program contains for every module one subroutine that contains:

- input data: signals, waveforms, recordings of the trend type;

- recorded data: signals, waveforms, recordings of the trend type;

- functions performed: the signal control, signal pre-processing, triggering of the signals, analysis of the signals and recording of the results.

2.1. Monitoring the part diameter

The part diameter monitoring module is the one who has the direct control on the output of the grinding process, that part dimension. The part dimensions monitoring module contains:

- measuring head, composed of two modules symmetrical to the rotation axis of the processing part and each module contain an inductive displacement transducer, with the race of ± 0.5 mm;

- a hydraulic device assures his introduction and removal from post;

- an analogue signal conditioning module; the acquisition module NI PCI 9233.

To the part diameter monitoring module was attached the precision function, which provide the stop of the processing when it reached the prescribed size. The processing is realised in a closed loop, a negative reaction is providing the control over the manufacturing process, through change orders of the cutting regime parameters and of the stopping process when the difference between the processed part dimension and the part reference dimension becomes 0.

The information about the evolution of the processed part diameter is displayed in real time, both in digital format and analogue.

The program for monitoring the part diameter has also a part diameter analysis menu, based on tracking the evolution in real time of the displacement transducers signals, as well as their sum, that represents the diameter.

Signals analysis measured provides important information about the part form, leading to the screening of the form errors causes.

The waveform analysis, presented in the diagram time – waveform, followed the evolution of the measuring signals T1, T2 and T1+T2, during a rotation of the part, base time being given by the pulses of a rotation transducer.

3. THE MONITORING OF THE ABRASIVE DISC

3.1. The monitoring of the vibrations

The abrasive stone has a non-uniform structure, being composed by abrasive grains, binder and eye pores, every new stone needs be balanced before being installed on the grinding machine. As a rule, the abrasive disk bears, before the mounting, a static balancing, on a balancing stall, subsequent balancing are necessary, as the active zone of the abrasive disk is consumed.

By research has been developed a manual balancing method, directly on the grinding machine, without using the static balancing stand. Accelerometers were used as vibration transducers, with the following characteristics: the measurement range: ± 10g, sensitivity: 500±10% mV/g, frequency range: 1-12 KHz. Experimentally, it was found that the abrasive stone unbalancing is owed to eccentric masses, situated in the interval 5 – 50 g, the initial state was of an unbalanced disk. The balancing method used is based on adding calibration weights, because, as it is the first calibration, there were no influence coefficients determined (Abalaru et al. 2008, Hao et al. 2001).

Have been monitored the parameters of the fundamental components (amplitude, phase and frequency) of vibrations picked up at the bearings level. In order to determine these parameters, FFT analysis was used synchronized with the abrasive stone rotary speed.

The balancing cycle on the grinding machine RU 100 has covered the following stages:

-analysis of the waveform of initial vibrations of the abrasive disk, with only one weight;

-analysis of the frequency spectrum of initial vibrations of the abrasive disk;

-editing of the polar diagram of initial vibrations;

-reading of the values of the angular position and of the mass of the disk unbalancing;

-positioning of the second balancing weight;

-editing of the polar diagrams of final vibrations;

-editing of the frequency spectrum of the vibrations after attaching the balancing weight.

It was found that the principal vibration source is constituted by the unbalancing of the disk showed by the frequency component equal to its rotation speed (fist order). The vibrations level is comparatively equal in the two bearings, 0.58 mm/s in the bearing 1 and 0.66 mm/s in the bearing 2. The frequency of initial vibrations that produce the unbalancing is 26.76 Hz, corresponding to the rotating speed equal to 1605 rpm of the abrasive disk.

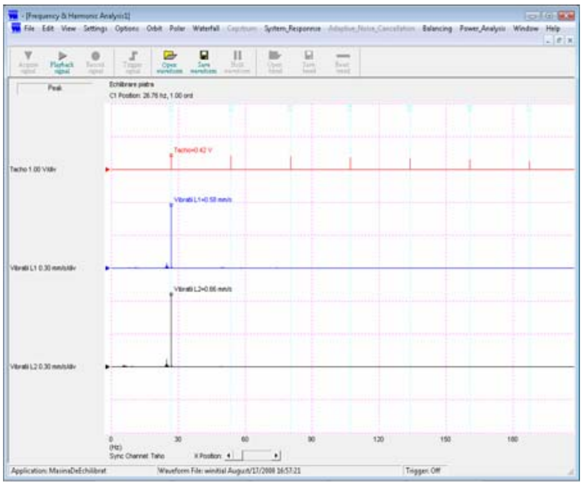


Fig.1. The frequency spectrum of initial vibrations, in the bearings of abrasive stone

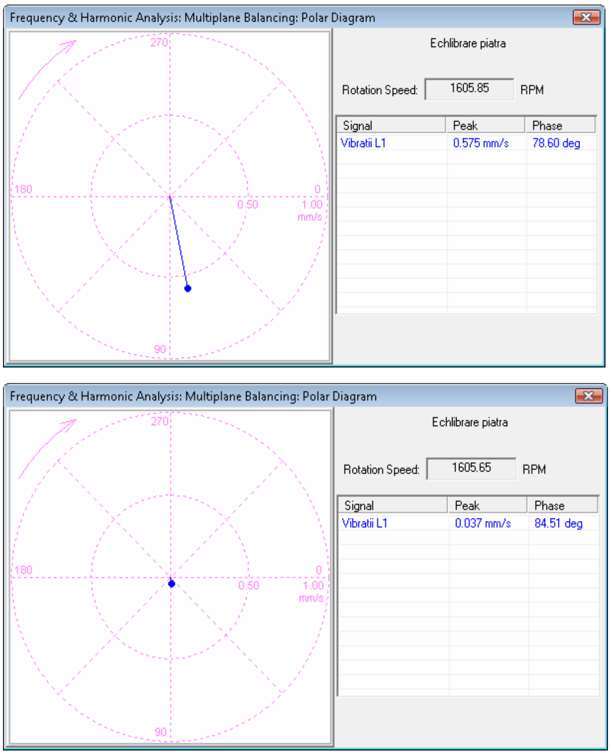


Fig.2. The polar diagram of initial vibrations (a) and after balancing (b)

In the polar diagram of the fig. 2 (a), it can be seen the level and the phase of the vibration vector, due to the unbalancing of the stone: top – 0.575 mm/s and phase – 78.60 grams.

The number of calibration operations is equal to the number of calibration plans.

The balancing was performed in only a plane, using as input dates the vibrations of the bearing 1. As a phase reference the signal proportional to the rotation speed of an abrasive disk was used. The calibration operation consisted in fixing an already known mass at an angle and radius already known and in measuring the vibration level.

In the case of large initial unbalancing, when the balancing operation does not lead to the imposed values after the first calibration, the calibration can be continued, by considering the new values as initial values.

Significant decrease of vibrations can be seen after the balancing, the polar diagram shown in figure 5 (b) shows a peak of 0.037 mm/s, accountable to the initial peak of 0.575 mm/s. This out-of-balance can be adjusted with corresponding weights, positioned at the angle resulting from the polar diagram.

A significant diminution of vibrations in the two bearings after only one balancing operation can be remarked, so in the bearing 1, the vibrations amplitude was reduced from 0.58 mm/s to 0.04 mm/s and in the bearing 2 it was reduced from 0.66 mm/s to 0.06 mm/s.

3.2. Monitoring of acoustic emissions generated during the manufacturing process

The grinding tool is characterized by a high number of cutting edges that bear a non-uniform wear, which leads to a non-steady process. The wear state of the stone is an important parameter of the grinding process. The loss of cut leads to the warming of the manufactured part, the increase of the resulting surface roughness, the increase of the duration of the manufacturing processes.

The abrasive disk passes through three principal wear phases, from the putting in operation till correction: the early-life phase, in which the grains are very sharp, but use quickly; the useful life phase, characterized by normal roughness of the grains, and by the fact that the degradation is slower; the end-of-life phase, when the stone degrades at an accelerated rate and because the roughness state of the stone is directly responsible for the power absorption and for the development of heat, with negative effects on the stone, this wear stage must be totally avoided, the abrasive disk being corrected or replaced before this situation happens..

The acoustic emissions generated by the abrasive stone at the contact with the manufactured part are used for the control and optimization of processing system. The detection, recognizing and measurement of the transmission level allow us: the control of the distance from the stone to the part; the control of the stone sharpening; assuring of the accurate macro and micro-geometry of the processed part's surface.

The acoustic emissions monitoring subsystem followed the evolution of the cut process in all three phases: new re-sharpened disk, disk with normal cut ability, and disk with advanced wear.

There were used, for the qualitative and quantitative analysis of acoustic emissions: analysis of the waveform and the spectral analysis (FFT).

In order to monitor the acoustic emissions, a set of two piezoelectric transducers, working in the band 20 – 200 KHz and 200 - 600 KHz, were used.

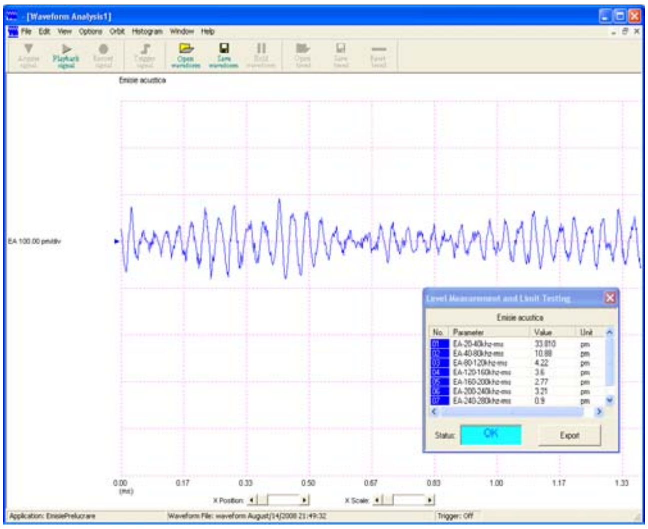


Fig.3. The waveform of acoustic emissions – new disk processing

Nr.	The parameter, *rms*	Values	Units
1	EA – 20 – 40 KHz	33.810	pm
2	EA - 40 – 80 KHz	10.88	Pm
3	EA - 80 – 120 KHz	4.22	Pm
4	EA - 120 – 160 KHz	3.6	Pm
5	EA - 160 – 200 KHz	2.77	Pm
6	EA - 200 – 240 KHz	3.21	Pm
7	EA - 240 – 280 KHz	0.9	Pm

The monitoring of the acoustic emissions level is made by using 7 programmable frequency bands, for every of these looking for the rms level, and framing in the pre-established limits.

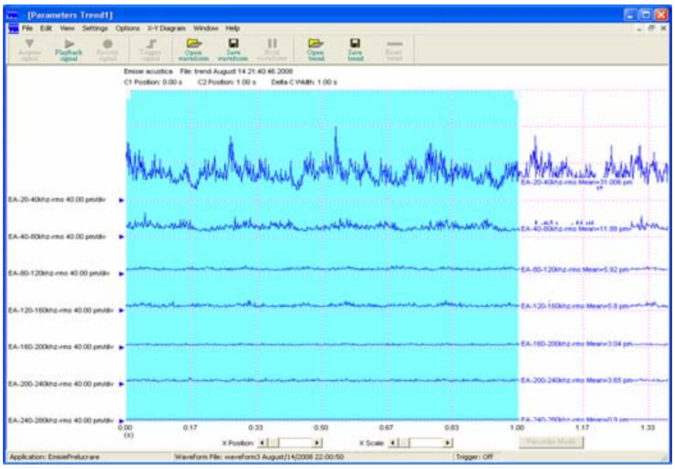
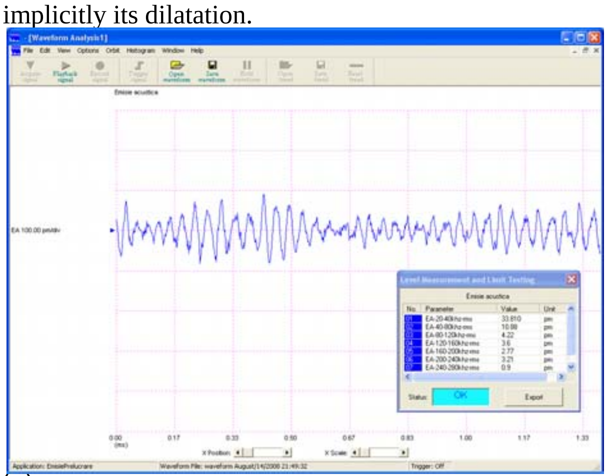


Fig.4. The acoustic emissions during the cut

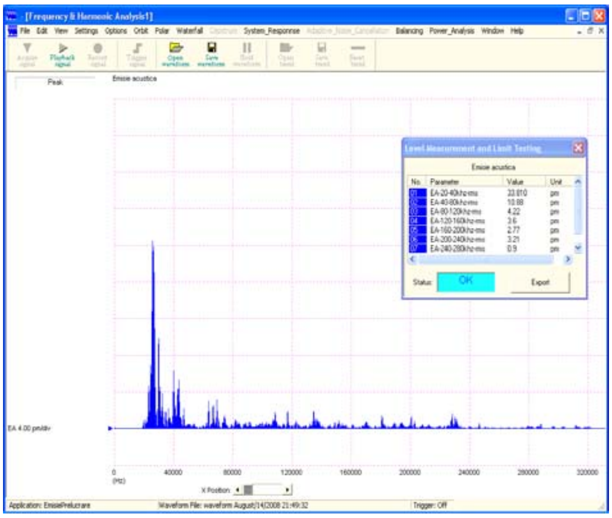
According to figure 4 the 7 frequency bands covered the intervals: 20 – 40 KHz, 40 – 80 KHz, 80 – 120 KHz, 120 – 160 KHz, 160 – 200 KHz, 200 – 240 KHz, 240 – 280 KHz.

The acoustic emission in the band 20 – 40 KHz is characterized by the highest level for rms. The rms level decreases as the frequency band increases, being relatively equal in the interval 80 – 240 KHz.

The finishing process has continued till losing the cut ability, when the abrasion between the disk and the part leads to the increase of the part temperature and implicitly its dilatation.



(a)



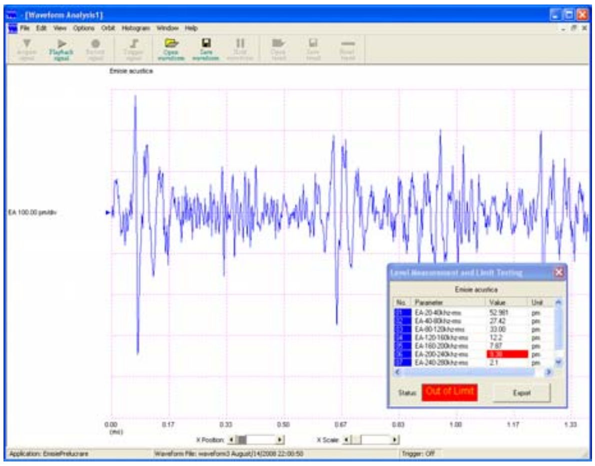
(b)

Fig.5. The waveform (a) and frequency spectrum of acoustic emissions– processing new stone (b)

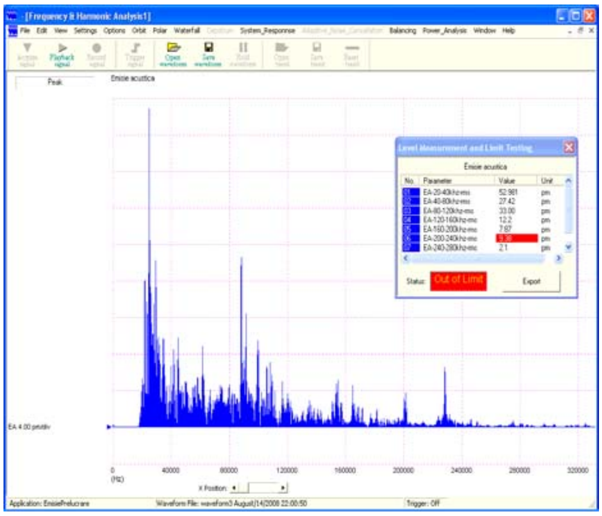
When the stone is freshly corrected, the frequency spectrum looks similar to the figure 5 (a), uniform enough, with a peak in the zone 25 KHz. The rms values in the interval 80 – 240 KHz are quite closed.

As the wear of the abrasive disk increases, the value of the parameter rms increases in the higher frequency bands, 80 – 120 KHz, 160 – 200 KHz and 200 – 240 KHz, 33.00 pm, 7.87 pm and respectively 9.38 pm (out of limit), figure 5 (b).

The frequency spectrum of acoustic emissions, when processing with a used disk has the form showed in figure 6, with peaks in the same frequency bands: 25 KHz, 80 – 120 KHz, 160 – 200 KHz, 200 – 240 KHz. While the value rms, in the 20 – 40 KHz band, grew only 1.5 times, in the higher bands it grew almost 3 times.



(a)



(b)

Fig.6. The waveform (a) and frequency spectrum of acoustic emissions– processing used stone (b)

The increase of the rms value in the high frequency bands can be used for the monitoring of the acoustic emissions generated during the cut, the processing stopping only when the correction of the disk must be done, when the rms level overpasses the admitted limit.

3.3 The monitoring of the stone profile

The processing, being the final finishing operation for reaching the imposed conditions, it's necessary to correspond to the type of material that is being processed, and it's roughness, and to have a corresponding geometry, without circularity or eccentricity errors.

Studies have been centred on the evaluation of the profile of the abrasive disc, with disc profile monitoring module, for extracting and analyzing harmonics, which indicates the errors of the profile of the disc.

The element that reads the profile of the disc is a laser transducer that measures using the triangulation method, and has the following characteristics: base distance: 45 mm; measuring domain: 50mm; linearity: 0.01% in the domain; resolution: 0.01% in the domain;

exit signal: 1 ... 10 V; sampling rate: 5 KHz. The disc profile monitoring module has the following elements: triangulation laser sensor, fixing and adjustment 2D module, acquisition module NI PCI 9233, process computer SIMATIC 507.

We are interested in the profile modification of the disc, the type of deviation that it has, because the deviations of the disc will influence the shape of the part that is being processed. The evaluation is made after the correction operation, when the disc is "clean" and has no worn grains that lost their cutting capacity.

The USB PCI 9233 interface received the measuring signal emitted by the laser, which was positioned at half the width of the abrasive disc, simultaneously with the signal form the revolution and faze transducer. A meridian circle of the abrasive disc in motion (1610 rev/min) was optically palpated, the increases emphasizing the gaps, and the decreases the edges of the abrasive grains.

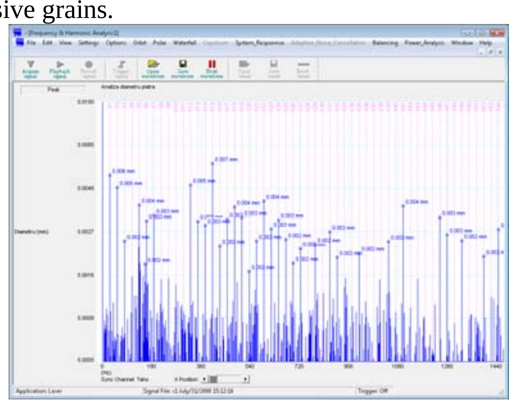


Fig. 7 The frequency spectrum of the laser sensor signal

The frequency spectrum of the laser signal (fig. 7) presents the high-order harmonics that indicate amplitude and frequency of irregularities appearance on at one rotation, and the low-order harmonics, that indicate the level of eccentricity and ovality of the stone. The form deviations are distinguished by filtering with a low-pas filter.

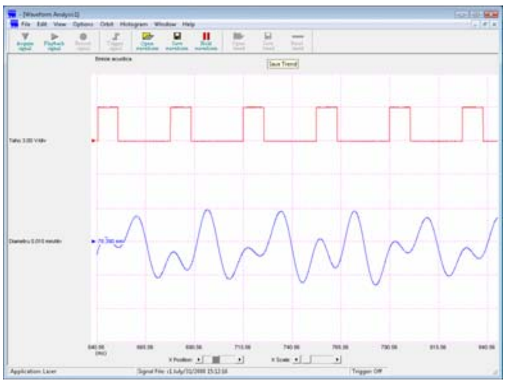


Fig. 8 The waveform of the laser signal

The wave shape represents signal variations for one rotation of the abrasive disc.

The signal analysis in the frequency domain emphasizes the distribution on different oscillation frequency.

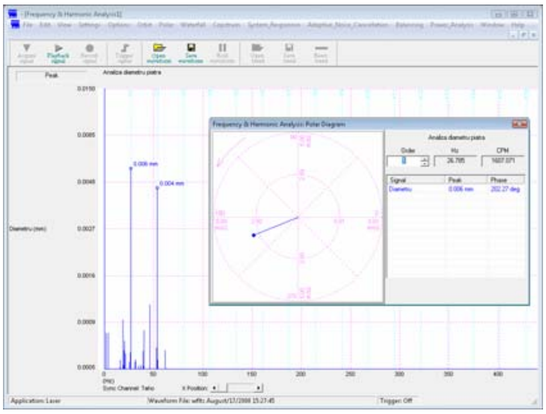


Fig. 9 The frequency spectrum filtered low-pas

The identification and localisation of deviation from circularity are realised by analysis of the low-order harmonics in connection with part rotation and phase.

The amplitude of the spectral components can be monitored individually or on frequency bands and utilized for optimizing the rectification process of the stone with the diamond tool.

Fig. 10 Vibro-acoustic and dimensional monitoring system

TECHNICAL FUNCTIONAL FEATURES:

Measuring capability:

Vibrations Range: 1- 10 KHz
Acoustic Emissions Range: 40-300 KHz

Diameters Range: 10-100 mm
Output commands: 5
The system monitoring stops the grinding process when part processed is reaching the settled dimension

APPLICABILITY:

- system will be integrated on the grinding machines
- optimization of the grinding process
- increasing of the grinding precision

growth the work productivity

4. REFERENCES

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