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# Autonomous System of Vibro-Acoustic Monitoring of the Grinding Process to Increase the Quality of the Processed Parts

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**Abstract:** This paper presents a modular self vibro-acoustic system for monitoring of the process of finishing by grinding to increase the quality of grinded parts. This system can be easily reconfigured and it can be used for other types of processing.

*Keywords:* vibro-acoustic monitoring, grinding, increased quality.

## 1. INTRODUCTION

The paper aims to present a real time vibro-acoustical and dimensional monitoring , diagnosis, system, based on high speed microprocessors, advanced sensors, software and high performance processing strategies, realised by research activity; the system integrated in the grinding process, is a strong built, flexible, capable to optimize the process parameters and to answer in real time at the process variations.
Our team has researched and realised a method and an apparatus that assure the multi-parametrical monitoring of grinding system, embedding the dimensional, vibrations, acoustic temperature, rotation sensors and software specialised, in the means to maintain the process in strong limits. The system controls the base elements of grinding process: the part geometry and the vibration, acoustic emission level and geometry of the abrasive stone.

## 2. THE MONITORING OF THE GRINDING PROCESS

The grinding process is an important step in finishing stage of a manufacturing process, which assures high geometric accuracy for the four possible errors (dimensions, form, mutual position, quality of the surface) to the processed parts. It is important to have a continuous monitoring of the finishing process so that it can intervene in the most rapid and effective way, when disturbance factors occurs.
Two components were monitored in the grinding process: the output of the process, respectively the processed part, and the abrasive disk, the active element, consumed during the manufacturing process.
The monitored parameters represented different physical variables:

-The acoustic emissions released during the processing time, with a slow change rate; the significant changes appear once with the advancing of the wear process of the abrasive disk;
-The vibrations which appear in the bearings of the abrasive disk, as a consequence of the loss of the equilibrium state;
-The dimension of the part which continually change by processing, the change rate of dimensions generally having the order 0.005 – 0.02 mm/s;
-The abrasive disk profile (measured after every adjustment action). (Abalaru et al. 2008, Batako et al. 2007)

## 3. THE ELEMENTS OF THE MONITORING PROGRAM

The monitoring system, composed by independent modules, with an open architecture, treated in a unitary way the four parameters of the manufacturing process, even if they represents different physical variables: vibrations, noises, dimensions, smooth surfaces. The monitoring program contains four subroutines, for the four parameters under observation, selectable on the monitor of the industrial board computer, SIMATIC type. The menu of every monitoring subroutine contains (fig. 1):

-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.

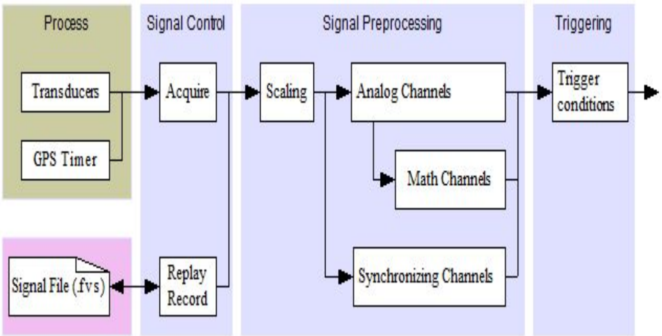



Fig. 1 The representation of the functions.

The abrasive disk which is the fundamental component of the grinding process and belongs to the consumable tools category, for this reason the correction of the profile is needed at the loss of the cutting ability.

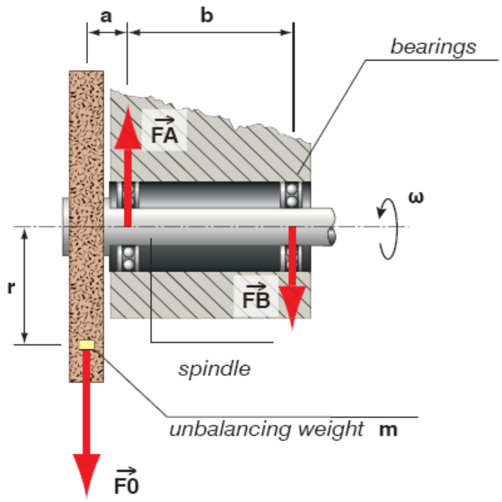



Fig. 2 Grinding wheel and its bearings.

The abrasive disk has a non-uniform structure, being composed by abrasive grains, binder and eye pores, every new disk 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.
The research aimed the development of a manual balancing method, directly on the grinding machine, without using the static balancing stand. Piezoelectric accelerometers were used as vibration transducers, with the following characteristics: the measurement range: ± 10g, sensitivity: 500±10% mV/g, frequency range: 1-12 KHz, output impedance: 200Ω. Experimentally, it was found that the abrasive disk 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).
The input entries are 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 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.

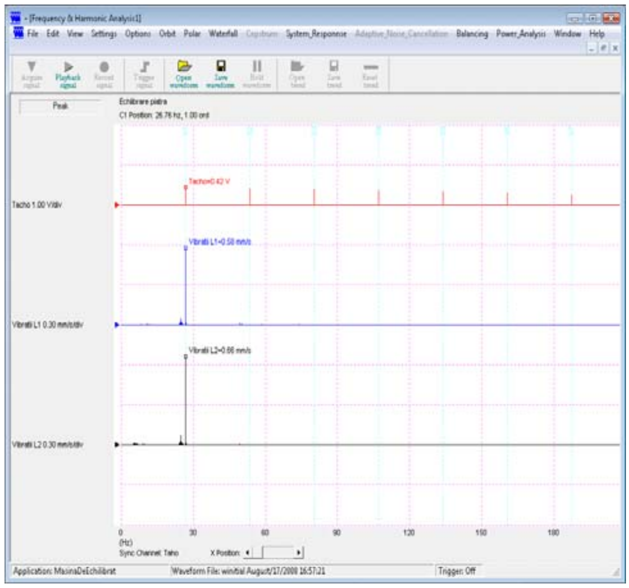


Fig. 3 The frequency spectrum of initial vibrations, in the bearings of abrasive disk.

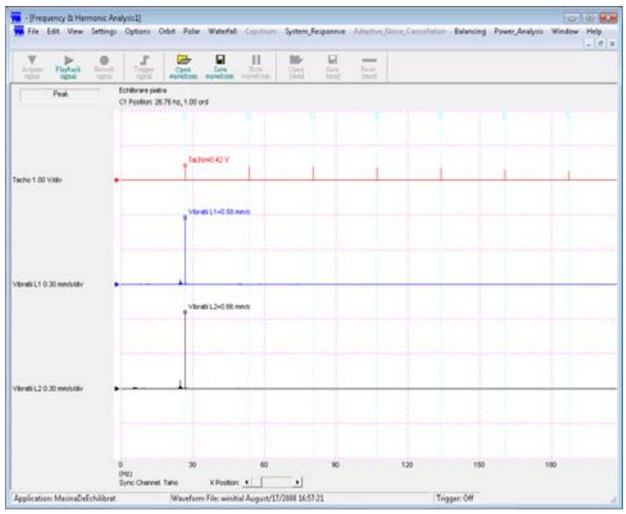
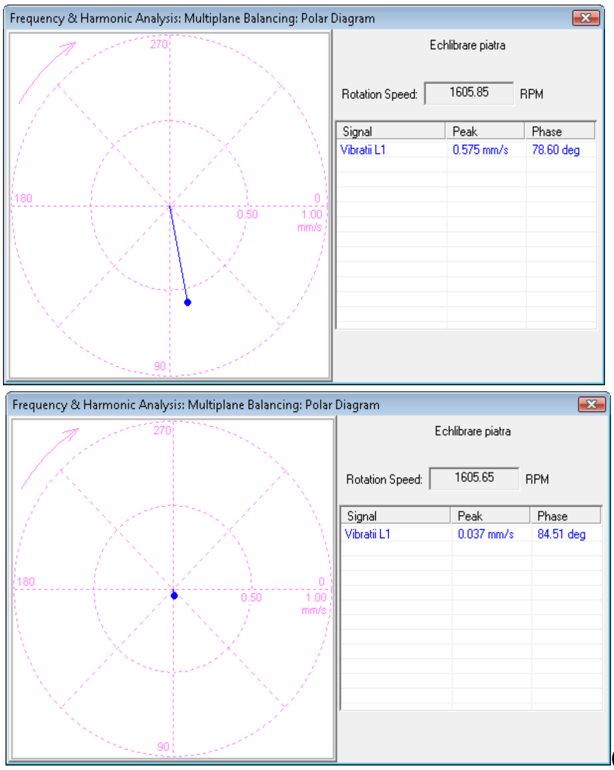


Fig. 4 The frequency spectrum of initial vibrations

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 (Kwak et al. 2002, Aguiar et al 2006, Sporer 2006).




(a)

(b)

Fig. 5. The polar diagram of initial vibrations (a) and after balancing (b).

In the polar diagram of the fig. 5 (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.

## 4. 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, (Abalaru et al. 2008, Batako et al. 2007) 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 (Becker et al., Kumaraswany et al. 2002).

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.

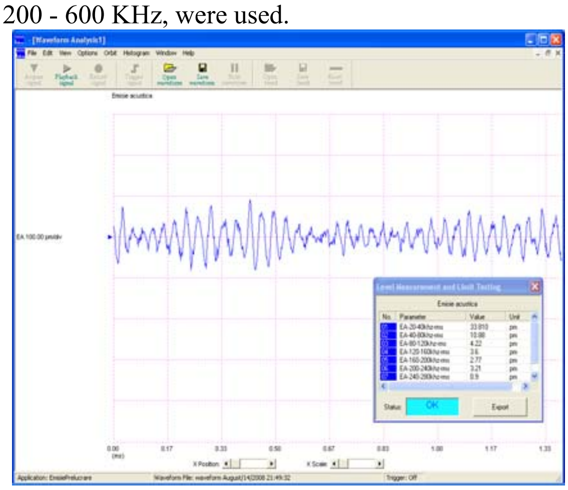


Fig. 6 The waveform of acoustic emissions – new disk processing.

Table 1

| 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.

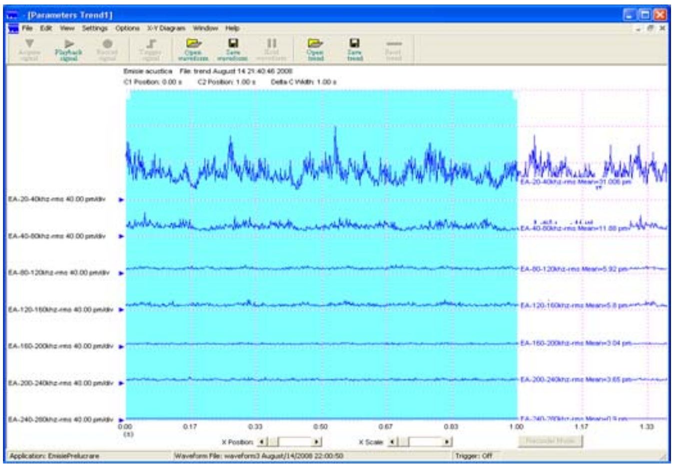
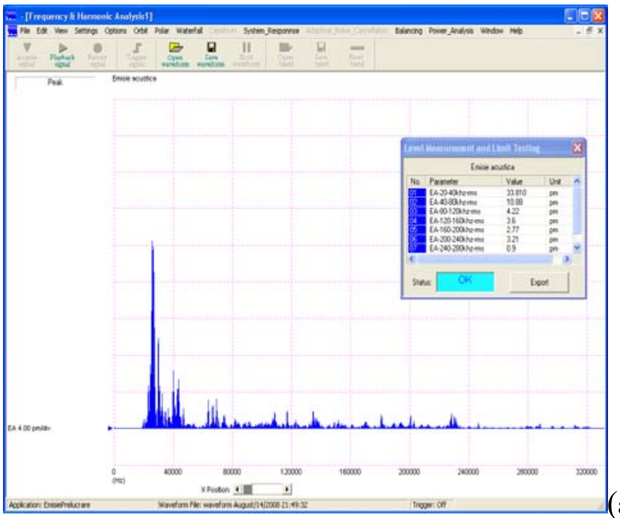
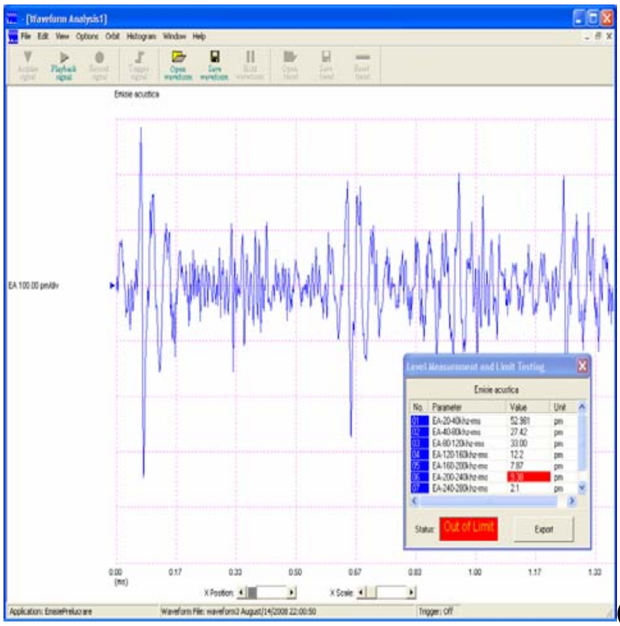


Fig. 7. The acoustic emissions during the cut.

According to figure 7 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. 8. The frequency spectrum of acoustic emissions– processing new disk (a) and the used disk (b).

When the stone is freshly corrected, the frequency spectrum looks similar to the figure 8 (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 8 (b).
The frequency spectrum of acoustic emissions, when processing with a used disk has the form showed in figure 9, 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.

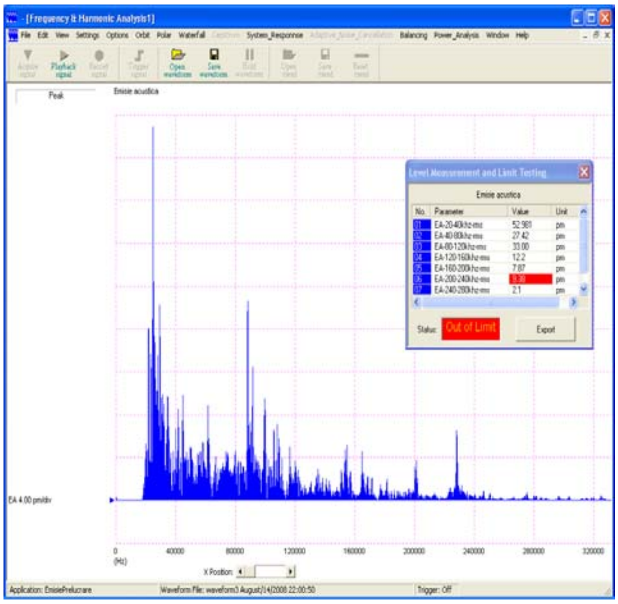


Fig. 9. The frequency spectrum of emissions – with used disk processing.

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.

## 5. MONITORING THE PART DIAMETER

The part diameter monitoring module is the one who has the direct control on the output variable of the grinding process, that size dimension. If the vibro-acoustic monitoring is realized regularly, after a number of processed parts, the monitoring of the diameter during the processing is realized permanently, for obtaining parts with dimensions within a very tight tolerance field (0.001...0.002 mm). The part dimensions monitoring module made is composed of: measuring head, composed of two modules symmetrical to the axis of rotation of the processing part, each module contain an inductive displacement transducer type HB, with the race of ± 0.5 mm; hydraulic device introduction and removal from post; 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 (figure 10), the 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 reference part dimension becomes 0.

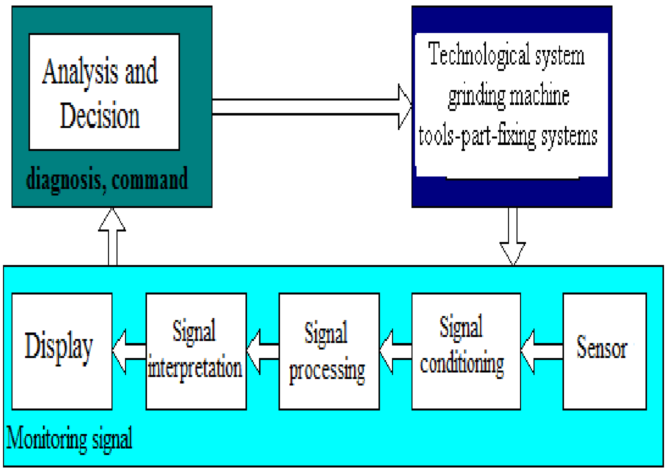



Fig. 10. The control loop of the manufacturing process.

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 transducer signals, as well as their sum, that of the diameter.

Signals analysis measurement provides important information about the part form, leading to the screening of the form causes errors.
The analysis waveform, embodied in the diagram time – waveform, followed the evolution of the measuring signals T1, T2 and T1+T2, during a rotation of the part, time base being given by the pulses of a rotation transducer.

## 6. THE MONITORING OF THE ABRASIVE DISC

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 (Becker et al.).
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.
The wave shape represents signal variations for one rotation of the abrasive disc.

### *6.1 The analysis of the frequency spectrum*

The signal analysis in the frequency domain emphasizes the distribution on different oscillation frequency.
The higher order harmonics indicates the amplitude and frequency of irregularities appearance at a complete rotation (the diameter of the stone).
The evolution of the low frequency components indicates the eccentricity and ovality of the abrasive disc.
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.

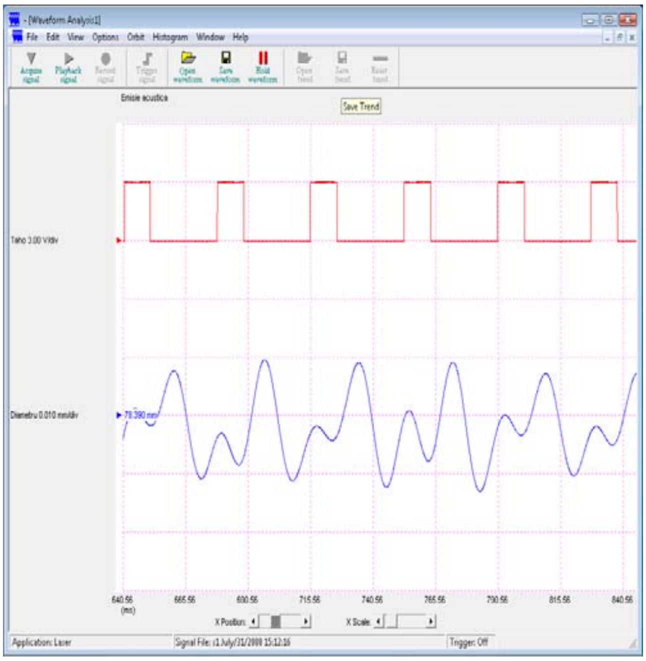


Fig. 11. The frequency response for shape deviation.

For emphasizing the low frequency shape deviations, a low pass filter has been used, which filtered the higher frequency components, and the wave shape of the signal emitted by the laser was obtained, figure 11, for the shape deviations, in which we can see the two low frequency components.

The low frequency harmonics analysis, in relation with the revolution and faze given by the revolution sensor, permitted the shape determination of the first harmonics, and the errors of the abrasive disc: eccentricity: 0.006mm; ovality 0.004 mm. The analysis gives important information to the operator of the grinding machine.

The abrasive disc profile monitoring assures profile evaluation of the disc, and extraction of the main harmonics responsible for apparition of the shape errors (eccentricity and ovality) which has negative consequences on the precision of the rectification.

The system made from easily reconfigurable modules, permits the adaptation for any type of processing, and integration in an automated processing system which main goal is increasing the quality of the processed parts, thru continuous non-contact monitoring (Wowk, Vibration Reference Guide).

REFERENCES

Abalaru, A., Stanciu, D., Dontu, O., Besnea, D., Increase machining precision in grinding process by vibrations monitoring. Revista de Mecatronica, nr.1, 2008.

Aguiar, P., Dotto, F., Serni, P. (2006). In Process Grinding Monitoring through Acoustic Emission.

Batako, A.D.L.,Koppal, S. (2007). Process monitoring in high efficiency deep grinding – HEDG.

Becker , J., Friemuth, T.,Tonshoff, K. Proces Monitoring in Grinding.

Friedman, A. An Intoduction to Linear and Non Linear Systems and their Relation to Machinery Faults.

Hao, Z., XiaoQi, C., Wildermuth, D. (2001). In Process Tool Monitoring through Acoustic Emission Sensing.

Kumaraswamy, S., Nalavade, K., Rakesh, J. (2002). Standardization of Absolute vibration Level and Damage Factors for Machinery Health Monitoring.

Kwak, J.S., Ha, M.K. (2002). Intelligent Diagnosis of Grinding State Using AE and Power Signals.

Sporer Adalbert. (2006). Optimising the grinding process.