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SOFTWARE PROGRAM FOR MACHINE CONDITION MONITORING BASED ON VIBRATIONS ANALYSIS

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Abstract: *The paper presents the structure of a software program developed for monitoring and assessment of industrial equipment condition, based on vibration analysis. Vibrations analysis methods used to detect faults are presented.*
Keywords: *Condition Based Maintenance; Machine Monitoring; Vibrations Analysis.*

1. INTRODUCTION

All mechanical systems in motion generate a vibration profile that reflects the operating conditions of the equipment. Vibration profile analysis is a useful tool in developing a predictive maintenance system and to diagnose faults of mechanical components.

2. VIBRATIONS MONITORING

Equipment vibrations are due to periodic or quasi-periodic events that occur during operation: shafts rotation, gears meshing, bearings rotation, rotary electric fields, engines and pumps operating cycles, etc. Knowing the frequency at which these events occur, the vibrations associated with these events can be identified. A change in the level of vibration of a certain frequency, indicate the occurrence of a failure, which may be located. In all vibration monitoring systems, the basic procedure is based on profiling the vibration of the new machine (or in normal operation conditions) and tracking the changes in the vibrations profile [3].

Depending on how the vibrations data are collected and analyzed, the monitoring can be **continuous** or **intermittent** [2].

Continuous monitoring is used only for the critical equipment of the production process, which must be stopped immediately if an imminent failure is indicated by a change of the vibrations profile. The advantage of continuous monitoring is that it responds very rapidly to unexpected defects which can't be predicted. Disadvantages of continuous monitoring are:

- high cost of permanent mounted sensors;
- the monitoring is based on the analysis of relatively simple parameters (RMS or peak value), which are calculated and analyzed quickly, but not provide a too large margin of time until the occurrence of the impending fault.

Intermittent monitoring is used for most machines. Vibrations data are manually collected at predetermined intervals, using a single vibration sensor and a portable data acquisition system, and then are processed off line. Advantages of intermittent monitoring are:

- low cost of monitoring equipment;
- advanced analysis techniques are used, providing a greater margin of time until the occurrence of the fault.

Disadvantages of intermittent monitoring are:

- can't be used when equipment failure is unpredictable because unexpected defects, that occur quickly, are not detected;
- depending on the monitored equipment, the data acquisition interval must be chosen carefully, both technical and economic considerations.

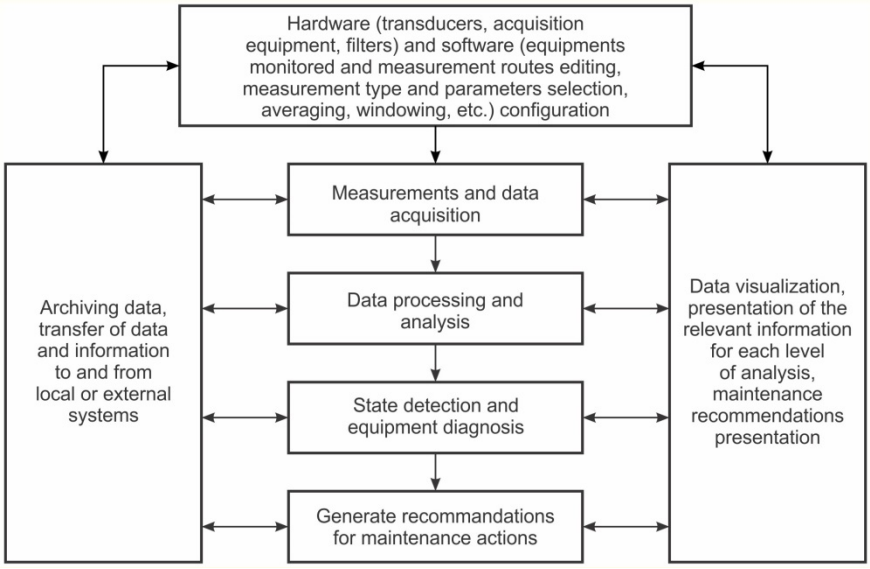

Fig. 1 Functional blocks of the vibration-based condition monitoring software

3. FUNCTIONAL BLOCKS OF VIBRATION-BASED CONDITION MONITORING SOFTWARE

Functional structure of the condition monitoring software based on vibration analysis is shown in Figure 1.

The kernel of the condition monitoring software consists of 4 functional blocks, each block providing a certain level of information processing:

- **measuring and data acquisition block**: the measurement hardware transform the tracked physical quantity (displacement, velocity or acceleration of vibration) in a digital parameter that can be processed numerically;
- **data processing and analysis block**: performs signal processing and analysis (filtering, averaging, windowing, FFT, cepstrum, envelope detection and signal demodulation) and calculates the significant descriptors for evaluation of various faults; depending on the acquisition equipment, some of the processing and analysis techniques may be used at the level of the measurement and acquisition block;
- **state detection and equipment diagnosis block**: performs fault diagnosis and establish the severity of the occurred faults by comparing the processed data with reference values, alert and alarm limits;
- **maintenance recommendations block**: establish the necessary maintenance actions to remedy the arising defects or to extend the proper functioning of equipment, based on the assessment of equipment condition monitoring and taking into account other external constraints (personnel safety requirements, environmental safety requirements, budgetary requirements).

The kernel of the condition monitoring software communicates with the external environment through 3 other functional blocks:

- **system configuration block**: allows the configuration of the operating parameters of the measurement hardware (transducers and equipment acquisition) as well as the configuration of the monitoring software: editing the monitored equipments and measurement routes, choosing the type and the parameters of the vibration measurement;
- **data and informations transfer block**: provides the archiving of the data and informations (measurements data, processed and analyzed data) and the transfer to and from other systems, local or external;
- **data visualization block**: provides the visualization of the data and informations relevant to each level of processing and analysis.

4. USED VIBRATION ANALYSIS TECHNIQUE

The complex vibration signals are analyzed in:

- the time domain:
  - assessment of the overall vibrations level and trend;
  - cepstrum analysis;
- the frequency domain:
  - FFT spectrum analysis;
  - envelope detection and signal demodulation.

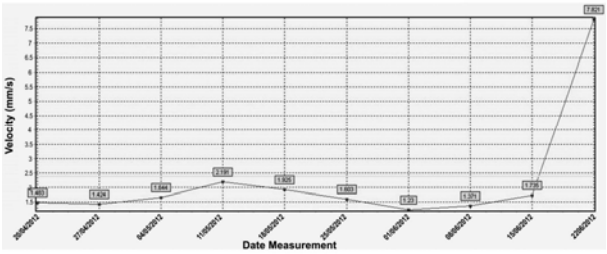

Fig. 2 Overall vibrations level evolution

The overall vibrations level and the evolution in time (trending) provides information on the overall condition of the monitored equipment (Fig. 2). The vibration level is assessed by comparing the measured values with alarm limits prescribed according to ISO 10816-1:1995 and to equipment manufacturers' recommendations.

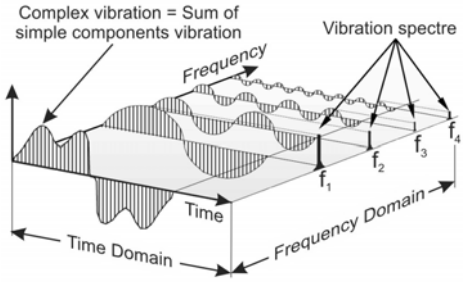

Fig. 3 Decomposition of vibration signal using FFT

FFT spectrum analysis is a general method of vibration analysis that is used to detect and diagnose faults. Complex vibration signal is decomposed into harmonic signals of different frequencies (Fig. 3). The obtained vibrations profile is compared with the set out reference vibrations profiles (alert and alarm profiles). By identifying vibration frequencies with high amplitude and comparison with the characteristic vibration profile of possible failures modes, the detection and diagnosis of faults is achieved (Fig. 4). To detect and diagnose low frequency vibrations faults (imbalances, misalignments, mechanical looseness) vibration velocity spectrum is analyzed. To diagnose medium and high frequency vibrations faults (bearing faults, gear mesh faults) vibration acceleration spectrum is analyzed.

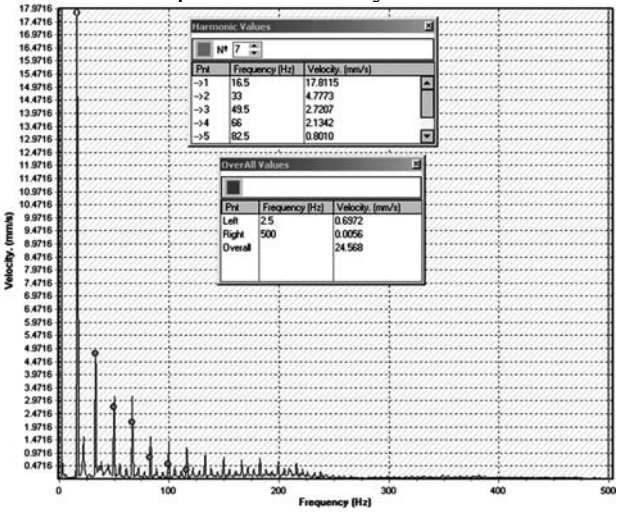

Fig. 4 FFT spectrum for a fan

Envelope detection and signal demodulation is a vibration analysis method used to detect gear and bearing failures, which are characterized by high frequency vibrations due to mechanical impact.

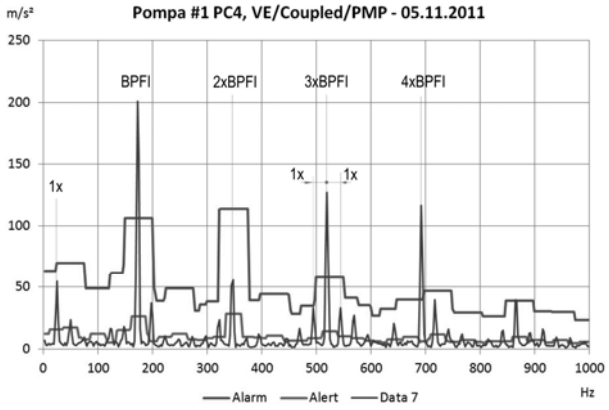

Fig. 5 Envelope spectrum for a pump bearing

The acceleration of vibration is the measured physical quantity. In the first stage of development, the gears and bearings faults occur at a high frequency with several sidebands due to the modulation of vibration amplitude. The modulating frequencies correspond to the faults characteristic frequencies. Acquired vibration signal is passed through a band pass filter, after which the carrier frequency is removed from the signal (demodulation), obtaining a

composed signal of low frequencies that initially modulate the signal. Analyzing these frequencies in a FFT spectrum of the envelope and comparing them with the characteristic frequencies of faults in bearings and gears, these defects can be detected at an early stage (Fig. 5). The presence of harmonics and sidebands in the original FFT spectrum is essential for the successful use of the envelope detection technique [1].

Cepstrum analysis is a post-processing computing and analyzing technique that can be applied to any FFT or envelope spectrum [4]. In essence, the cepstrum is a technique of constructing a "spectrum of a logarithmic spectrum", respectively is an inverse Fourier transform which returns the vibration signal in the time domain.

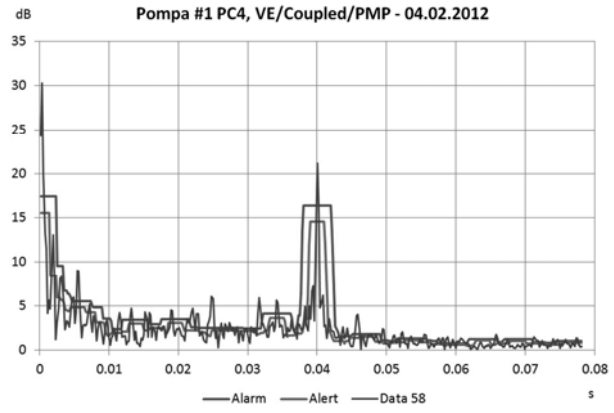

Fig. 6 Vibration acceleration cepstrum

Using cepstrum technique, the sidebands and the corresponding peaks can be easily identified. For each family of harmonics or sidebands, resulting data consist of only one line, so that it easier to identify the fault. [4].

Cepstrum analysis method is not sensitive to the position of the measurement and to the monitored equipment's loads.

5. CONCLUSION

In machine condition monitoring systems based on vibration analysis, the selection of the processing and data analysis techniques, as well as the selections of features used, is based on the characteristics of the monitored equipment so that possible defects to be more easily detected. Isolation and identification of faults (establishing defective items in an assembly) using only classical processing and analysis techniques is very difficult.

6. ACKNOWLEDGMENT

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Program software de analiză a stării echipamentelor industriale pe baza vibrațiilor

Rezumat: Articolul prezintă structura unui program software realizat pentru monitorizarea şi evaluarea stării echipamentelor industriale bazat pe analiza vibrațiilor. Sunt prezentate şi metodele de analiză a vibrațiilor utilizate în detectarea defectelor.

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