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FAULTS DETECTION AND DIAGNOSTICS ALGORITHM USED IN A VIBRATIONS BASED CONDITION MONITORING SOFTWARE

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Abstract: *The paper presents a faults detection and diagnostics algorithm used in a machine condition monitoring software program, based on vibration analysis. A vibrations analysis case study for a motor-pump assembly is presented.*
Key words: *condition monitoring, vibrations analysis; fault detection; fault diagnostic.*

1. INTRODUCTION

Vibration profile analysis is a useful tool for monitoring the condition of industrial equipment and for the faults detection and diagnosis of mechanical components. The general condition of industrial equipment can be simple evaluated by comparing the overall measured vibration level with the overall reference vibrations level (alert or alarm levels) [3]. But the detection and diagnosis of occurring faults is a complex process requiring the simultaneous analysis of several series of measurements of vibration [1].

In principle, faults diagnosis is a mapping process of the information obtained in the space of vibrations measurements to possible defects from the space of monitoring faults [5]. This mapping process is also called as pattern recognition process. Traditionally, pattern recognition is done manually by direct visualization of graphs resulting from signal analysis (FFT spectrum of speed and acceleration, envelope spectrum, cepstrum, wavelet spectra, etc.). But the manual pattern recognition requires personnel with high expertise in the diagnosis of each type of monitored equipment. Therefore, it would be helpful if the pattern recognition process can be done automatically.

2. FAULTS DETECTION AND DIAGNOSTICS ALGORITHM

If vibration measurements are made and the data for these measurements are available, the assessment of the equipment condition and faults diagnosis using vibration analysis is performed according to the flowchart from Fig. 1, according to the following steps:

- select the monitored equipment whose condition will be evaluated;
- select the measuring point and the type of measurement to be analysed;
- download from the database the measurements data to be analysed; also download the reference and limits values (alerts and alarms) associated with the selected measurement point; necessary failure criteria are extracted or calculated from the measurement data;
- extracted or calculated failure criteria are compared with reference values and with alert and alarm limits;
- if failure criteria exceed the allowable values a preliminary analysis of these criteria is performed, and the criteria that can be associated with the occurrence of a fault are stored temporarily;

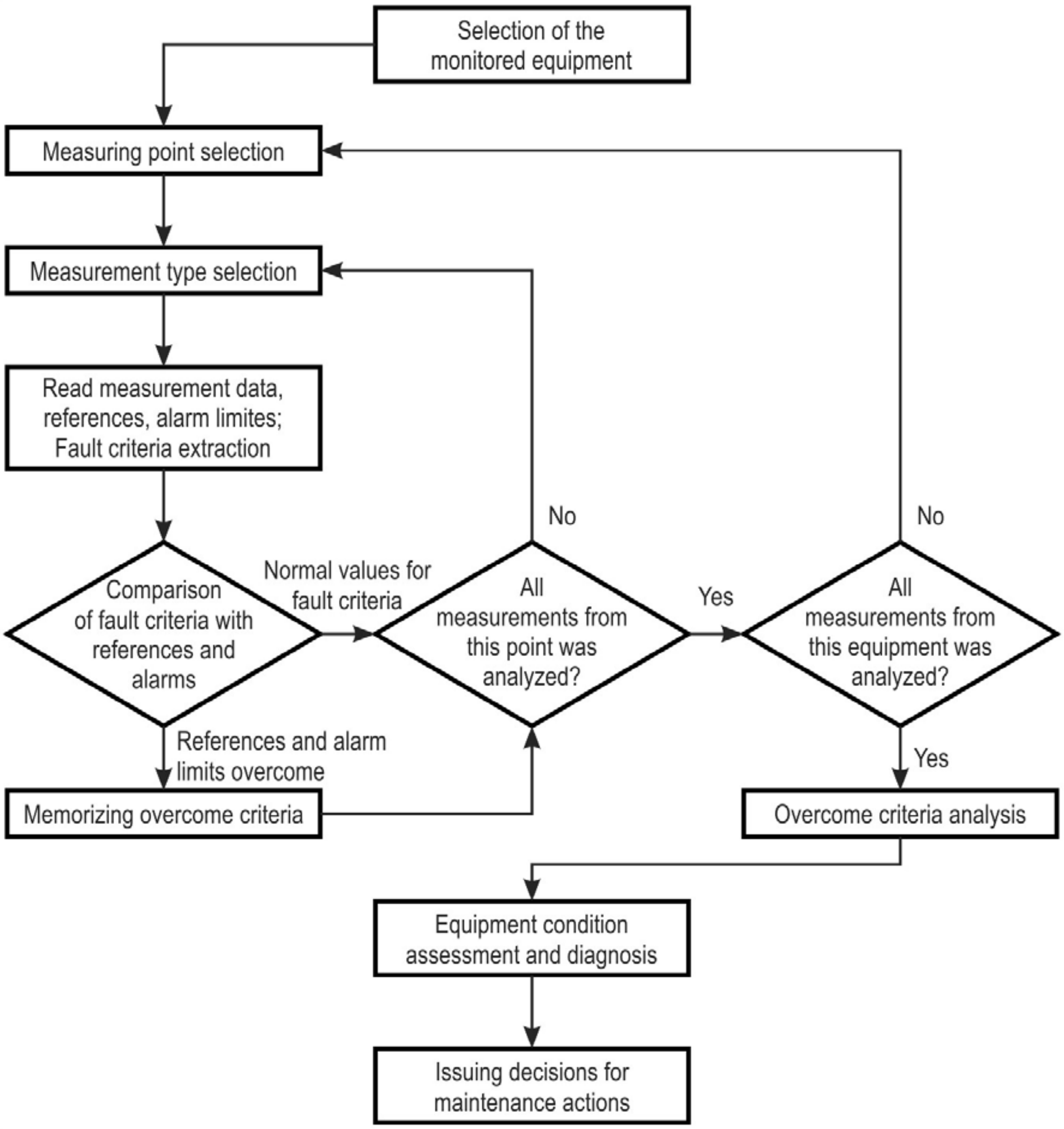

Fig. 1 Vibration based condition monitoring flowchart

- if all measurements associated with the measurement point were analyzed individually, is necessary to analyze the correlation between different failure criteria for different measurements type; the overcome fault criteria will be stored temporarily and move on to the next measuring point;
- the algorithm continues until all measurements from all monitoring points are analysed;
- on the basis of remaining failure criteria, the condition of the monitored equipment is assessed, the types of occurred defects are detected, the fault severity is assessed and the faulty subassemblies are identified.

Performing the assessment of the equipment condition after analysing all measurement points and after the correlation of the analysing conclusions from each point of measurement, the number of false alerts of failure can be reduced, which is an important advantage.

3. VIBRATION ANALYSIS FOR A MOTOR-PUMP ASSEMBLY – CASE STUDY

In a metallurgical company, machines vibrations are measured at regular intervals using the Brüel & Kjær data collector type 2526 and industrial accelerometers type 8325 or 8327. The portable data collector system is able to perform vibration analysis both in time domain (waveform analysis, cepstrum analysis) and frequency domain (FFT spectrum, the signal envelope detection) [6].

Data from measurements can be transferred into a database on a PC. Using vibration monitoring software, Brüel & Kjær Type 7107, measurement data can be viewed, and after their analysis by a specialized operator, various monitoring reports can be generated [6]. This monitoring software is not a software for the diagnosis of the monitored machines, but rather a configuration software for the data collector system and software for visualization of measured data [6]. In order to achieve automatic evaluation of machine condition monitoring and automatic diagnosis of occurring faults, a new software program for equipment condition monitoring based on vibration analysis was designed.

Data from vibration measurements made at the metallurgical company were reanalysed using the new software. The results of the new analysis were similar to those reached by the company's specialists in maintenance, using classical methods of analysis, experience and history of operating and equipment failure.

As an example, the following is such an analysis performed for a pump-motor assembly, whose fundamental rotation frequency is 24.97 Hz (1498 RPM). For such an assembly, the following measurements points were established:

- motor, free end (Free/MTR) – radial vertical direction measurement;
- motor, coupled end (Coupled/MTR) – radial vertical, radial horizontal and axial directions measurements;
- pump, coupled end (Coupled/PMP) – radial vertical and radial horizontal directions measurements;
- pump, free end (Free/PMP) – axial direction measurement.

For measurements in the radial horizontally direction and in the axial direction have been made only measurements of the vibration velocity (RMS value of FFT spectrum). For measurements in the vertical direction both velocity and acceleration of vibrations are analysed, and the analysis techniques used were the FFT spectrum, the envelope detection and the cepstrum of the vibrations signal.

During the monitoring period, for the vibrations measurements in radial horizontal and axial direction no overcomes of the alert or alarm limits were recorded. The vibrations measurements in the radial vertical direction, especially in the coupling area of the two components, showed a change in the vibration indicating the occurrence of a fault. Significant changes in the profiles of vibration occurred on two dates: 05.11.2011 and 04.02.2012.

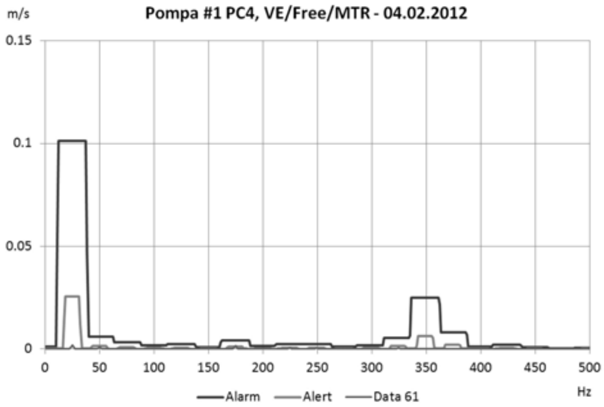

Fig. 2 Velocity FFT spectrum (RMS) – motor, free end, vertical direction

When measuring vibrations at the free end of the motor, the FFT spectrum of vibration velocity is unchanged (Fig. 2).

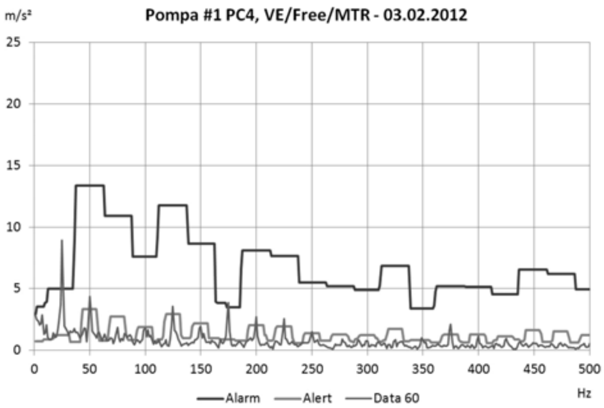

Fig. 3 Envelope detection, acceleration (Peak) – motor, free end, vertical direction

Analysing the envelope of the vibration acceleration several peaks are observed. These peaks correspond to harmonics of the fundamental frequency, that exceed one alert and even exceeds the alarm limit (Fig. 3), signalling a misalignment.

Vibration measurements made at the coupled end of the motor, highlights similar profiles at both ends (free and coupled end), but the magnitude of the vibration at the coupled end is larger (Fig. 4 and Fig. 5), which shows that the source of vibration is at the coupled end, due to the misalignment of coupled components.

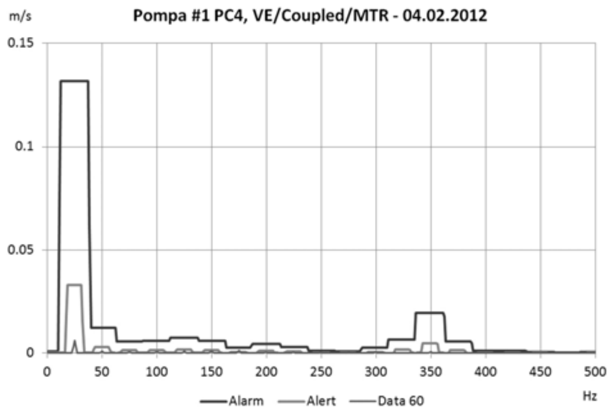

Fig. 4 Velocity FFT spectrum (RMS) – motor, coupled end, vertical direction

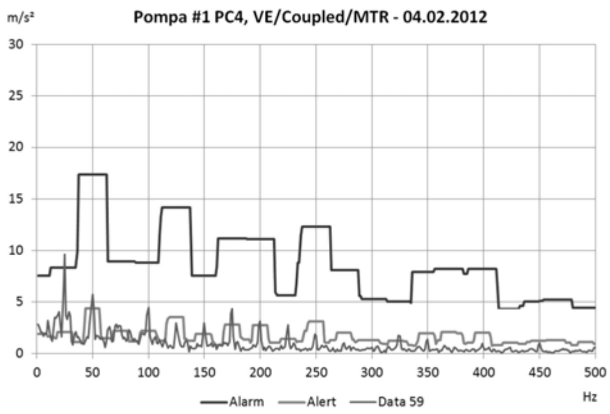

Fig. 5 Envelope detection, acceleration (Peak) – motor, coupled end, vertical direction

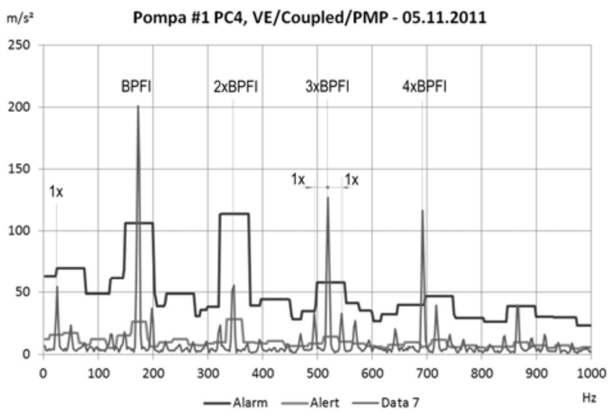

Fig. 6 Envelope detection, acceleration (Peak) – pump, coupled end, vertical direction

At acceleration envelope analysis on 05.11.2011, peaks are observed at the BPFI bearing defect frequency (6.9 x fundamental frequency) and 3-5 orders harmonics of this frequency and sidebands at 1x and 2x the fundamental frequency (Fig. 6).

The presence of these harmonics and sidebands indicates a defect of the rolling track of the inner ring. After bearing replacement, upper harmonics and sidebands disappeared from the spectrum (Fig. 7).

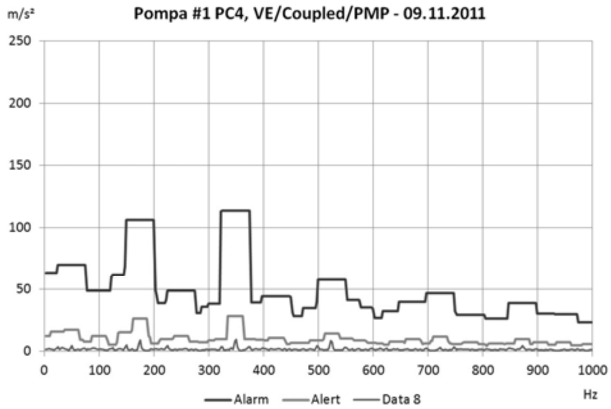

Fig. 7 Envelope detection, acceleration (Peak) – pump, coupled end, vertical direction; after bearing replacement

On 04.02.2012, the analysis of the frequency spectrum of velocity and acceleration at the coupled end of the pump does not show overruns of the alert and alarm profiles (Fig. 8, Fig. 9).

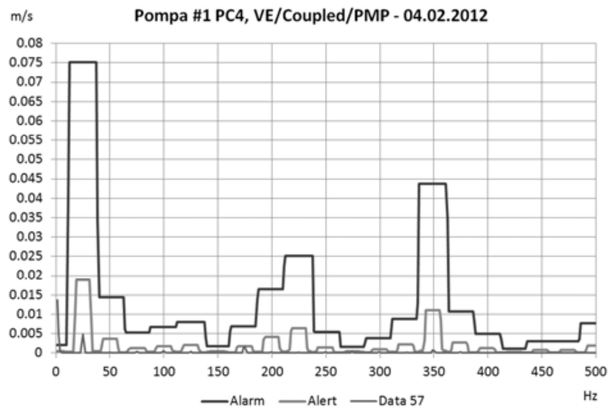

Fig. 8 Velocity FFT spectrum (RMS) – pump, coupled end, vertical direction

Analysing the acceleration cepstrum (Fig. 11), several peaks exceeding the alarm profile are observed. These peaks recorded at quefrencies 0.005664063, respectively 0.040039063, correspond to frequencies 24.9756 Hz (fundamental frequency of rotation) and 176.5517 Hz (blade pass frequency = 7 x fundamental frequency) signalling defects on the pump blades (valves).

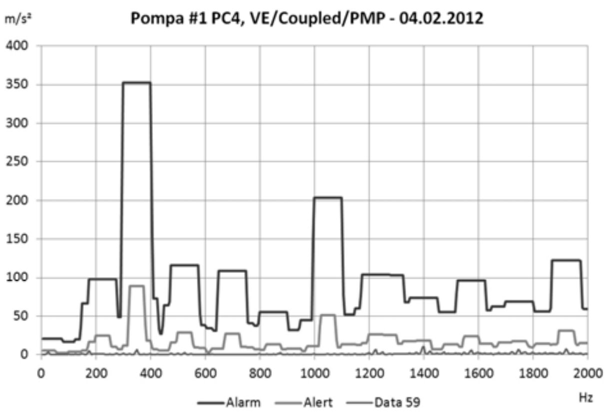

Fig. 9 Acceleration FFT spectrum (Peak) – pump, coupled end, vertical direction

The analysis of vibration signal envelope at the coupled end of the pump has no overruns of the alert or alarm profiles (Fig. 10).

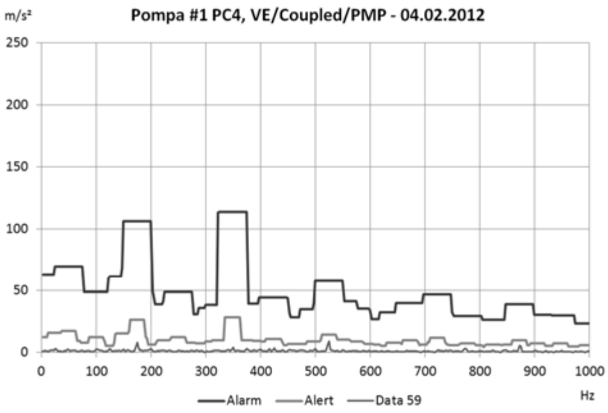

Fig. 10 Envelope detection acceleration (Peak) – pump, coupled end, vertical direction

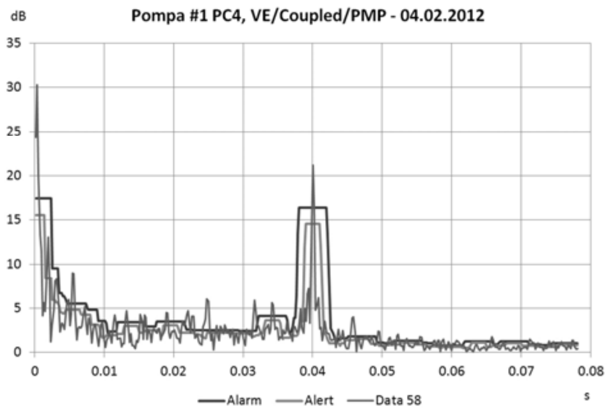

Fig. 11 Acceleration Cepstrum – pump, coupled end, vertical direction

The analysis of the vibrations profiles of motor-pump assembly #1 PC4 on 05.11.2011 concluded that the bearing from the input shaft of the pump had a defect of the rolling track of the inner ring. After the bearing replacement, vibration profile returned to normal. The rolling track of the inner ring of the replaced bearing present peeling.

The analysis of the vibrations profiles of motor-pump assembly #1 PC4 on 04.02.2012 led to the identification of the following faults:

- misalignment of the pump with the motor;
- failure of the pump blades.

The replacement of defective pump blades and the initiation of the alignment procedure of the two components (motor and pump) were recommended.

Using classical techniques of analysis, their experience and operating and failure history of equipment, the maintenance specialists of the metallurgical company identified the same defects at pump-motor assembly # 1 PC4 on 04.02.2012.

For each measurement made, the new condition monitoring software analyse the vibration profile of the monitored machine and extract the top 20 peaks of the spectrum. Based on the information recorded in the database on characteristic fault frequencies corresponding to each logical point of measurement, these 20 peaks are identified (fundamental frequency, harmonics, fault frequencies of the bearing, pass frequencies, mesh frequency). The vibrational profile corresponding to these frequencies are compared with the profiles of these specific failures, which were implemented in the program. Analysing the correspondence between this vibration profile with different specific failure profiles, the type and location of the occurred fault is determined. Compared with the existing monitoring software from the studied metallurgical company, the new developed condition monitoring software enables automatic detection and diagnosis of faults without human operator intervention.

4. CONCLUSION

In order to eliminate the human factor in assessing the equipment condition, a new vibration-based condition monitoring software was designed, to process and analyze the data so that the state assessment and diagnosis of faults would be automatic. For an accurate diagnosis and to increase the confidence in the diagnosis, several signal analysis techniques are used simultaneously. Vibration analysis techniques used in the new condition monitoring software are:

- FFT spectrum analysis of the vibrations signal;
- envelope detection and vibrations signal demodulation;
- cepstrum analysis.

The testing of the new condition monitoring software to monitor equipment status was done by processing and analysing multiple data sets resulting from vibration measurements. The diagnosis made by the new condition monitoring software was compared with the diagnostic performed by the company's maintenance personnel, at the time of the measurement. The faults diagnosed by the new condition monitoring software are the same as the fault diagnosed by maintenance personnel.

The above confirms that the chosen signals analysis techniques and condition assessment algorithm implemented in the new program can be used successfully in machine condition monitoring based on vibration analysis.

5. ACKNOWLEDGMENT

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Algoritm pentru detecția şi diagnosticarea defectelor utilizat în programul software de monitorizare a stării bazat pe analiza vibrațiilor

Rezumat: Articolul prezintă un algoritm de detecție şi diagnoză a defectelor echipamentelor industriale utilizat în programul software de monitorizare şi de evaluare a stării echipamentelor bazat pe analiza vibrațiilor. Un studiu de caz de analiză a vibrațiilor la un ansamblu motor-pompă este prezentat.

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