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Condition monitoring and fault diagnosis

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Abstract

The paper deals with detection of fault conditions based on measurements of vibration made on rotary machines in various industries. Detection of sources of vibration will be made based on the amplitude spectra and phase relationships of vibrations of individual machine parts, using the envelope of technology in detecting recurring events with low levels of the measured signal and processing of high-frequency signal in the range of acoustic emission. Because the display of a set of symptoms to the space of fault conditions for these methods is not simple, it is advisable to use a multi-parameter approach which means that important decisions are made on the basis of different types of measurements, for example, with using techniques of modal analysis and operational modal analysis. The paper presented the results of various measurements on the machinery.

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Keywords: vibration; spectrum; condition monitoring; modal analysis; excitation source;

1. Introduction

The risk of repeated failures machinery leads frequently to look for the causes of this phenomenon. If technologies are part of machines with rotating parts and there are indications to suggest high levels of vibration then one of the ways of eliminating these risks is to understand the symptoms of vibration. A common method is to measure vibration using accelerometers in selected points. The measured values provide initial information on the level of vibration and spectral properties. But such an analysis does not necessarily provide a satisfactory answer to the question of what is causing these vibrations and how to reduce or eliminate. The problem may be divided into three parts and analyzed as:

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- Excitation sources, such as internal: unbalance, misalignment, mechanical looseness, resonance, damage of bearings, gears, belts, excitation of hydraulic and aerodynamic forces, vibration caused by electrical problem etc. and external: other stimulus and also understanding the triggers that activate those resources as stimulus, [1-4].
- Transfer path to amplify, attenuate, respectively filters the excitation signal on the path from the source to the point of measurement.
- Vibrations at the point of measurement which are determined by the excitation signal and the modal properties of this place.

In the following part of the paper I will be presented on real outcomes measurement technology.

2. The detection of the vibration sources

The relationship between the event or fault conditions using the selected processing method and its symptoms is shown in Fig. 1. Difficulties may arise in ambiguous detection of a fault condition on the basis of established symptoms. Because the display of a set of symptoms to multiply fault conditions for these methods is not simple, it is advisable to use a multi-parameter approach which means that important decisions are made on the basis of different types of measurements.

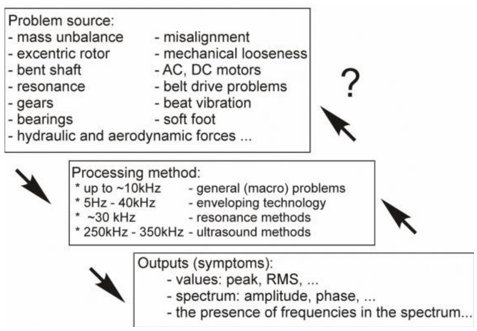

Fig. 1 The ambiguous detection of a fault condition on the basis of established symptoms.

A detection of sources of vibration will be made based on the amplitude spectra and phase relationships of vibration of individual machine parts. The results of some selected cases to identify the sources of vibration problems are presented by Fig. 2–6.

Kinematics scheme of cement mill gearboxes 2x1.6MW is shown by Fig. 2. They contain the indicated number of teeth and to the input speed of the gear are determined the tooth frequencies of the different gears.

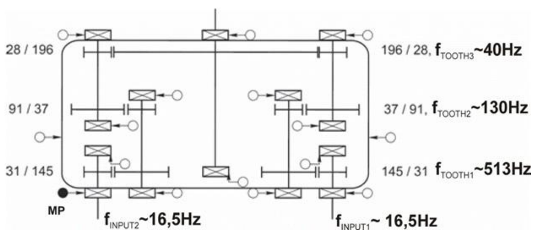

Fig. 2 The Kinematics scheme of cement mill gearboxes with numbers of teeth, the tooth frequencies and one of the measure points (MP).

During routine condition monitoring was obtained next spectrum too. The dominant frequency of the 2th gear tooth frequency and the 2th harmonic are present in the spectrum by Fig. 3. The high levels of these peaks are the result of a heavy-duty of this 2th gear at baseline in the gear Condition Monitoring program.

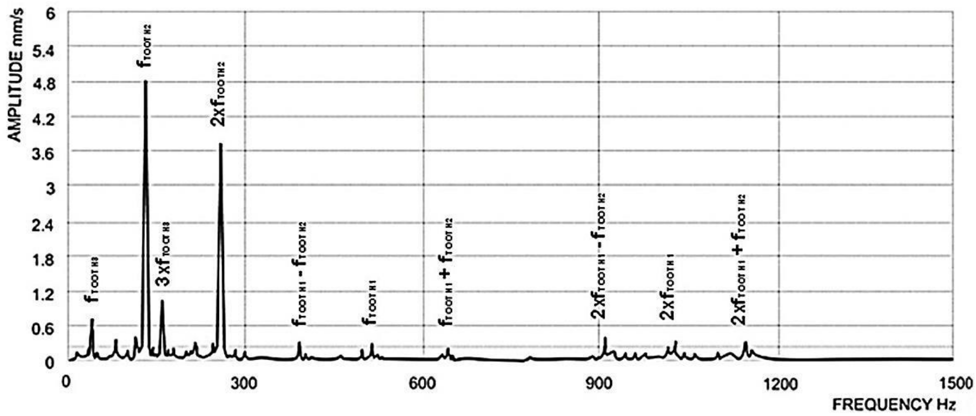

Fig. 3 The cement mill, the baseline spectrum with dominant frequency at the 2th gear tooth frequency with the 2th harmonic.

After a few months of operation: a huge increase in peak at a frequency 1th tooth frequency and the 2th harmonic of this frequency are present in the spectrum by Fig. 4. This gear of heavy-duty, force reactions are collected mainly in this gear. Approximately 100% increase in amplitude at a frequency 3th gear tooth frequency. It was recommended to open and inspect the gear teeth. This control was found tooth with a crack on the output wheel with 196 teeth. The assumption on the redistribution of power load in the gearbox was confirmed. This was a decrease of stiffness in the output gear and force reactions were collected in 1th gear.

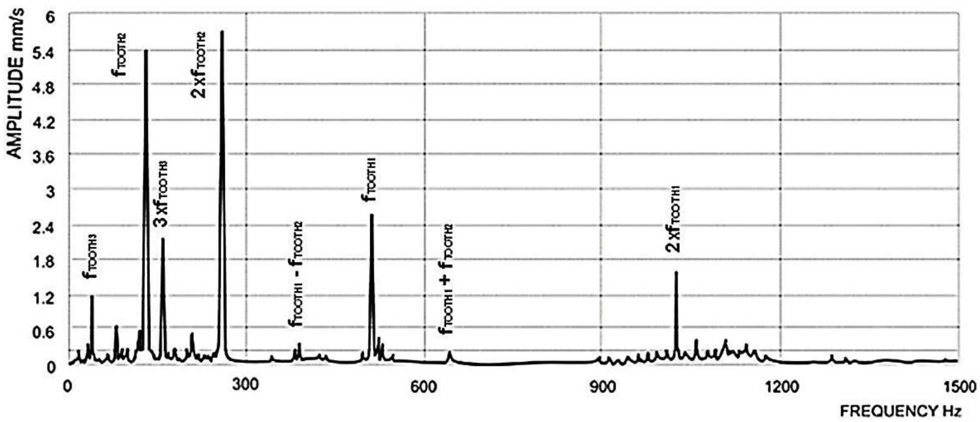

Fig. 4 The cement mill, increase in amplitude at a frequency 3th gear tooth frequency, the redistribution of power load in the gearbox.

The presence of bearing damage is identifiable in a vibration spectrum by rolling element bearing faults [1-3]: (BPFI - ball passing frequency inner race, BPFO - ball passing frequency outer race, BSF – ball spin frequency, FTF - fundamental train frequency (cage)).

By Fig. 5 is presented velocity spectrum of the input shaft bearing gearbox of ski-lift. A tooth frequency of the 1th (input) gear (199Hz) with its 2th harmonic (399Hz) is marked. A double sideband with carrier equal to 199 Hz is marked too. This double sideband indicate problem – defect on the outer ring for bearing 22315 of the input shaft.

If a bearing defect is present then signal that is generated by such a bearing also contains high harmonics but with low amplitude noise masked. Envelope technology that enables you to analyzed such a low level signal is described as follows [5]:

- filter out low frequency vibration components using a band pass filter (low frequency components are symptoms of macro problems such as unbalance, eccentric rotor, bent shaft, misalignment, mechanical looseness), frequency range band pass filter is selected by the shaft rotational frequency f_{OT} of the bearing so as to cover the range of high multiples of bearing defects,
- getting approximately square signals (increasing signal noise ratio),
- filter out high frequency vibration components using a low pass filter,
- signal is analyzed in the low frequency range.

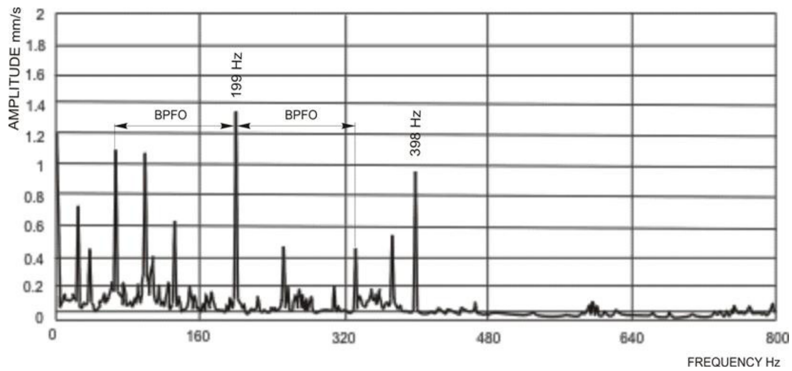

Fig. 5 The gearbox of ski-lift, the sideband around gear tooth frequency indicate defect on the outer ring for bearing 22315 of the input shaft.

Using enveloping technology for detection of bearing defects is illustrated on spectra from measurements on paper mill specifically for the bearing housings the drying section of a paper mill. The speeds of bearings were around 141rev/min and 96rev/min.

In the Fig. 6 the multiples BPFO for bearing 6315 are marked. There are isolated peaks, which due to the life of the bearing is considered the second stage of bearing damage using a scale with 4 stages.

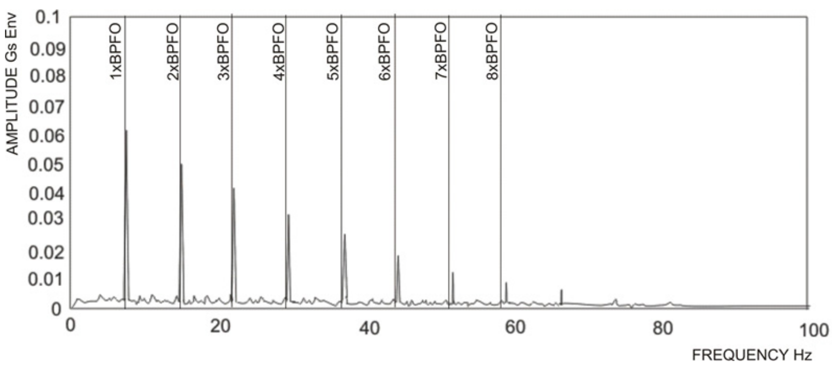

Fig. 6 Paper mill, the multiples BPFO for bearing 6315 are marked, defect on outer ring of bearing

In the Fig. 7 the multiples BPFI and BPFO for bearing 24060 (calender) are marked. They are not isolated amplitude, but clusters of amplitudes, which represent sideband on multiple BPFI. The distance sideband frequency corresponds to RPM of bearings.

Acoustic emission is generally processed signal in the frequency range 40kHz - 1MHz. The next cause is limited to the range of 250kHz - 250kHz , which uses the method SEE ® (Spectral Emitted Energy, the company SKF), to that extent, the signal detected in the metal-to-metal contact. We can consider two metal surfaces with micro-inequalities, with non-zero relative speed. As a result of contact pressure leads to micro-welding, which is subsequently breaking while releases energy in the form of detectable ultrasound transducer. The consequences of this phenomenon are beyond the frequency domain macro-problems and also outside the bearing resonance (30kHz - 40kHz, Spike energy method, SPM, HFD). Subsequently the signal (like when enveloping technology) is demodulated in the frequency range of bearing defects and its harmonics and can be processed using the FFT. In this way it is possible to evaluate the lubrication when high values of SEE are indicative of metal - metal contact and can be interpreted as a lack of lubrication. The signal is processed in the form of SEE units for which they are processed by the decision-making criteria regarding the status of particular bearing.

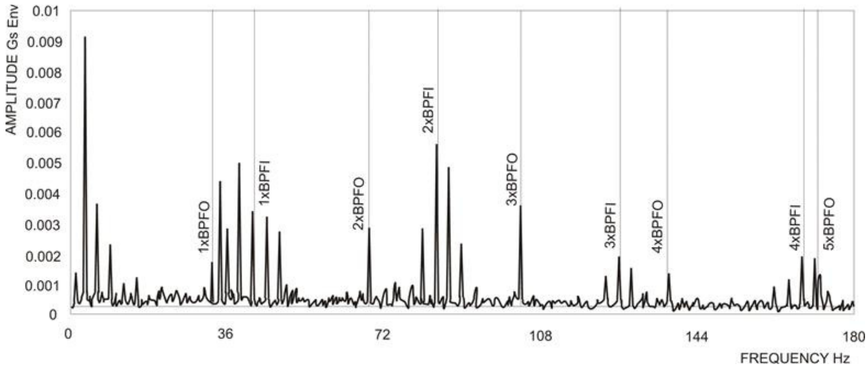

Fig. 7 Paper mill, the multiples BPFI and BPFO for bearing 24060 are marked, defect on outer and inner ring of bearing.

In the Fig. 8 SEE spectrum of bearing 239/500CAK/W33 is presented with remarked frequency of bearing defects on the inner ring, BPFI. Measurements were made at the paper mill on the suction cylinder

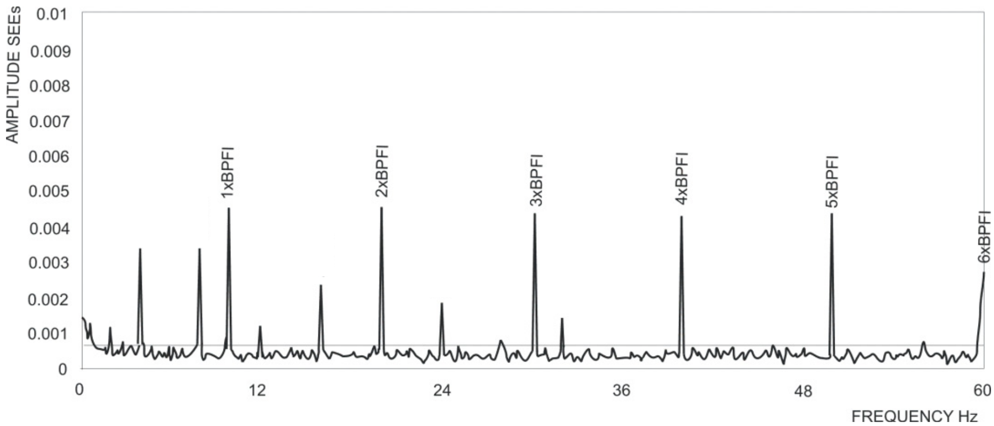

Fig. 8 Paper mill, the suction cylinder with the bearing 23248CK/C3, a problem with a lack of lubrication at inner ring.

3. The transfer path

Analysis of the transfer means and the identification Frequency response function (FRF) |is important not only in terms of the response of the excitation source at the measurement, for example, when there is a lack of diagnostics symptoms, but may be considered material and accomplish the task of suppressing the vibration at the measuring points. A simple method for estimating the FRF is considered bump test too.

The belt is a sensitive indicator of vibration in the mechanical system or even it appears as an amplifier of vibration. In Fig. 9 is depicted a frequency response function (FRF) of belt specifically the amplitude and the phase function. The resonance frequencies are indicated by two symptoms the peaks of amplitude at this frequencies and phase shift around 180deg at this frequencies too. If the motor run up (from 0 Hz to 200 Hz) or run down, then it transits through belt natural frequencies with temporary increasing sound and vibration of equipment and belt can be exciter the resonances in these transition states. The results of measure the FRF of are depicted by Fig. 9.

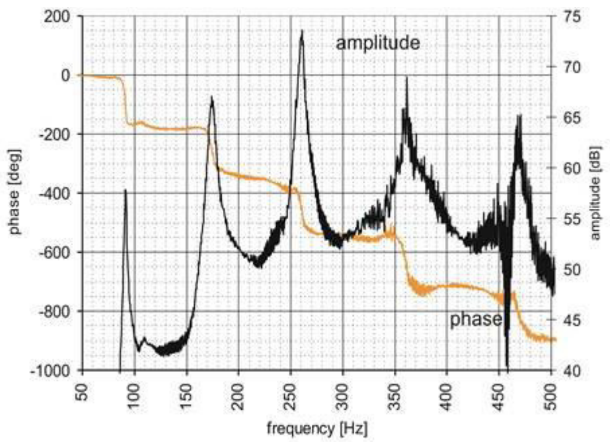

Fig. 9 The resonances of belt, the frequency response function, amplitude and phase.

The rotational parts are suspended in a cabinet with cover sheets by the springs and shock absorbers. The vibration of these rotational parts is transmitted through these elements in the sheets of the cabinets. FRF of shock absorber also characterizes the transmission path. In Fig. 10 a natural frequency of absorber is around 250 Hz. A signal, the source is inside the cabinet and which transmits from the inside to cover sheet trough the shock absorber may be amplified in the frequency range around this natural frequency. A coherence function takes the value equal to the unit, which corresponds to the linear model of the analysed system.

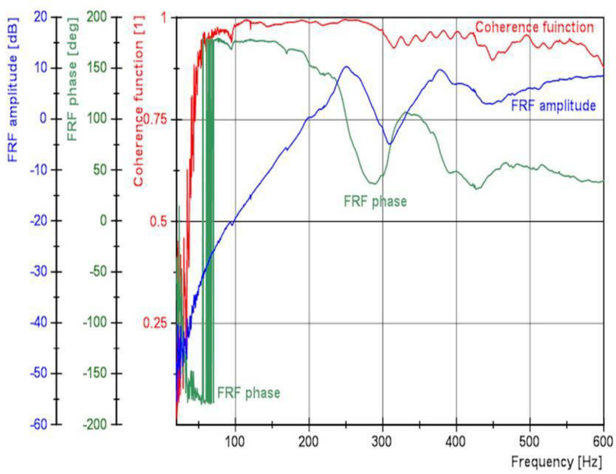

Fig. 10 The shock absorber, the FRF's - amplitude and phase and coherence function.

4. The understanding of modal properties of analyzed object

If the device is in operation and we have to do the measurements with sensors then the measured spectrum can be depicted by Fig. 10. The sensor is not placed near sources of vibration inside the cabinet, but only on the sheets. (Such the measure may be the result of vibration condition monitoring.) The acceleration spectrum measured on the sheet (a blue curve) is depicted at the bottom by Fig. 11, amplitude FRF (a green curve) is depicted at the top and phase FRF (a red curve) is depicted too. We can see that the background of vibration spectrum and peak of acceleration are significantly determined by modal properties of sheet. Acceleration spectrum was measured during operation of the machine and FRF was measured at stop stage the impulse hammer was used as an excitation of object. An accelerometer was placed in both measurements at the same location.

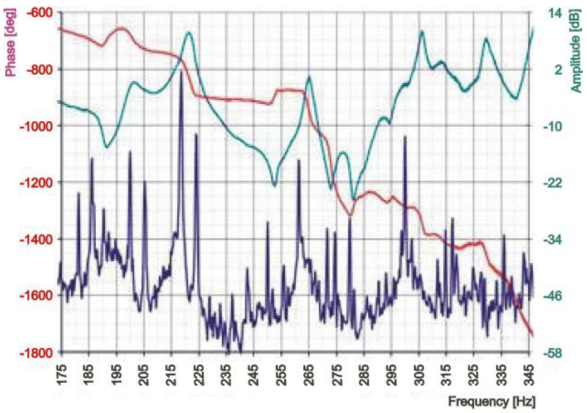

Fig. 11 The comparison of acceleration spectrum and amplitude FRF on the sheet of cabinet.

Problems objects are often initially identified on the basis of increased noise. It is then natural that is considered to solve the problem of noise. However, the high level background noise sometimes complicate or prevent measurement. By Fig. 12-13 are compared measurements agricultural tractor transmissions using accelerometer and microphone without using acoustic filter weighing. These figures present the qualitative consistency sources of noise and vibrations at the same frequency, but with different amplitudes, as shown in the different characteristics of the transmission paths from the source to the sensor.

5. The results

The paper discusses the problem detection of vibration source, transfer path and modal properties of analyzed object.

Some selected signal processing techniques were presented in the field of machine monitoring on the basis of vibration. Although these procedures are primarily maintenance support are also useful in solving scientific and research challenges in reducing or correcting noise and vibration.

In terms of noise and vibration reduction solutions they are also useful in detecting sources described transfer path and tuning external machine structure (through noise reduction issues have specific problems, for example due to the physiological characteristics).

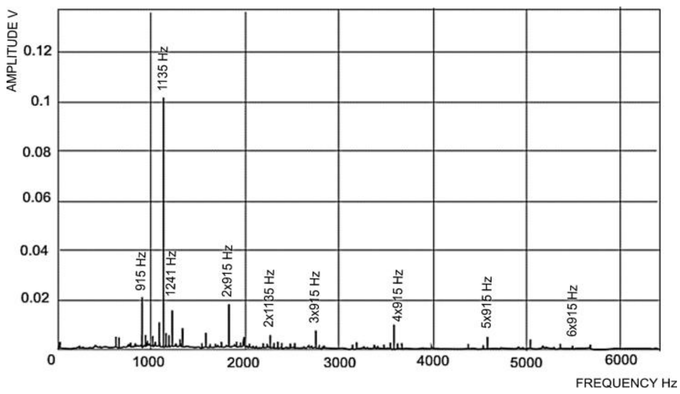

Fig. 12 The gearbox of farm tractor, output from microphone.

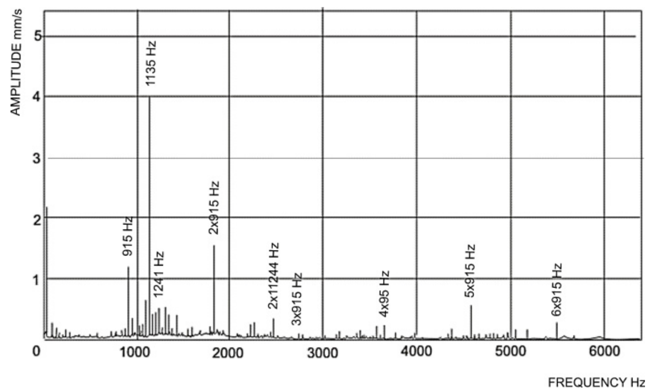

Fig.13 The gearbox of farm tractor, output from accelerometer after integration.

Acknowledgements

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