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ANALYSIS OF NON-STATIONARY VIBRATION MODE MECHANICAL DEVICE

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Abstract: *Presented article relates to principal mathematical methods in field of vibration research using computational software. Analysis of vibration and processing vibration signals by start-up (non-stationary mode) of mechanical device with purpose to detect vibration amplitude, effect of resonance and excitation of self-excited oscillations was performed. In this topic, there are listed a description and relevant approach serving for processing vibration signals. Core of this article is formed by make-ready data gained from real measurement, processing data through the calculation software, assembling computational algorithms for acquirement of results for next analysis and equation.*

Keywords: Vibration signal, Non-stationary mode, Mathematical algorithms, Analysis, Vibration amplitude and oscillation.

1. Introduction

Measurement, processing and analysis of the mechanical vibrations are principal part of the diagnostic system to monitor operating conditions of machinery in all industrial sectors. The aim of machinery diagnostics includes the detection of occurrence and causes of vibrations and subsequent elimination of the possibility of their occurrence with an effort to ensure life prediction and maximize the reliability of the machinery in operation (Sága, 2009).

Vibrations measurement is very important, as evidenced by the still more emphasis put on the analysis of vibrations and noise, as well as advancing the development of diagnostic machinery. Increased vibration affects the life cycle of machines and causes material stress leading to direct failure, but also has a detrimental effect on humans, whether in the form of noise or vibrations that are closely related. This means that the diagnostic of the vibration is important assessment methodology in all industrial sectors (Handrík, 2016).

In this paper, there is a procedure for investigation of the vibration behavior of specific mechanical device presented. Firstly, mathematical methods, which were used for solving and evaluating of measured data, were defined. Secondly, analysis of vibration signal with computational software through the algorithms on basis of specific mathematical methods was conducted and finally, obtained results and graphical contour with purpose to detect amplitudes, natural frequency, and effect of resonance were investigated.

2. The investigated mechanical device

The investigated machinery is rolling mill, which consists of reinforced ground, supporting steel structure, electric motor, gearbox and rolling cartridge. Power transmission between (gearbox and axle is secured by coupling shafts, which are connected to both end of the claw couplings. Drive the rolling

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cartridges is ensured by cardan shafts. The measurement was taken at the measuring point No. 1 in the axial direction.

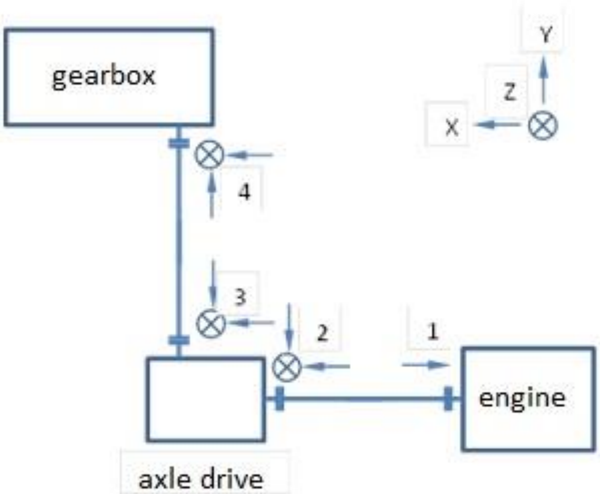

Fig. 1: The investigated rolling mill.

3. Mathematical methods

Fourier transform and its applications along with relying on wavelet transformations of various types are effective methods for processing various signals. Methods provide relevant information and results of the measurement data by applying appropriate mathematical algorithms of these methods using computer software. The results are graphic representations of the vibration signals in the time or frequency domain values with a possible detection of vibrations. The following paragraphs are different mathematical methods thoroughly described.

Short-time Fourier transform (STFT) is a tool for time-frequency analysis of non-stationary signals. The transformation provides information of the signal *f(t)* and its spectrum *F(ω)* in the time-frequency window. The principle of this method is that, by multiplying the signal *f(t)* to be analyzed with a certain type of symmetry of a window function (i.e. Window) $\omega * (t-\tau)$ of constant length, and the computation of the Fourier transform of the sections to the signal *f(t)* (Grigorian, 2009 and Samajova, 2015) is as follows:

$$STFT\{x(t)\}(\tau,\omega) \equiv X(\tau,\omega) = \int_{-\infty}^{\infty} f(t)\omega * (t-\tau)e^{-j\omega t}dt = < f(t).\,\omega * (t-\tau)e^{-j\omega t} >, \quad (1)$$

where the symbol (*) indicates complex conjugation and τ represents time offset of window.

Wavelet transformation consists of unfolding and folding the input signals via the function called wavelet. Wavelet is time-localized wave i.e. wave packet. Wavelet transform has all the features created from a single parent prototype basic wavelet *ψ(t)* by means of two basic operations scaling and offset in time contour (Qian, 2011).

$$SWT_f(a,b) = \int_{-\infty}^{\infty} f(t)\psi^*_{[a,b]}(t)dt = \langle f(t), \psi_{[a,b]}(t)\rangle \; a \in R^+, b \in R, \quad (2)$$

Wavelet transform of function $f(t) \in L^2(r), R = (-\infty, \infty)$ is defined as representation $L^2(R) \rightarrow L^2(R^2)$.

$L^2(a, b)$ is space, where squares of functions exist, are integral and finite.

4. Solution and evaluating the results

By the measurement process of rolling mill *6,228,215* data representing acceleration values was acquired. Sensor sampling rate was set to *25,600 kHz*, corresponding to a time step *t = 1 / f = 3.90625e-005 s*. Start-up, constant speed and run-out of the machinery (rolling mill) is shown in Fig. 2. Time dependent values of acceleration and the corresponding values of rotation speed (RPM) for about *243* s are displayed are in Fig. 2. From Fig. 2 it is clear that the start-up (non-stationary mode) of the machinery is performed at a time interval $< 0.75\ s >$, increasing the speed from *100* to approximately *1,500* revolutions per minute and having the current acceleration of *40 m/s*^{2}.

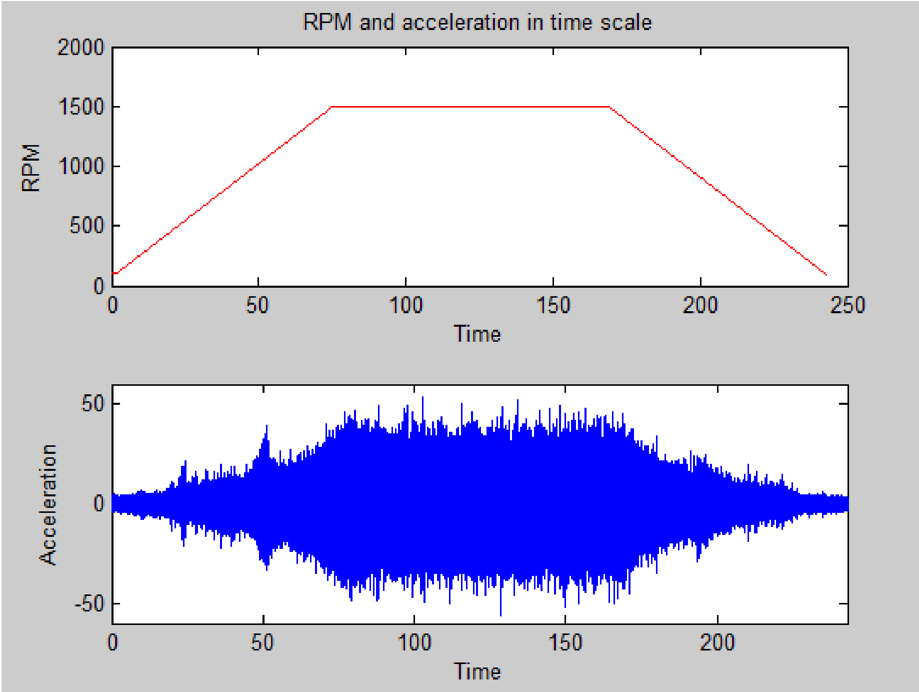

Fig. 2: Graphical contour of RPM and acceleration.

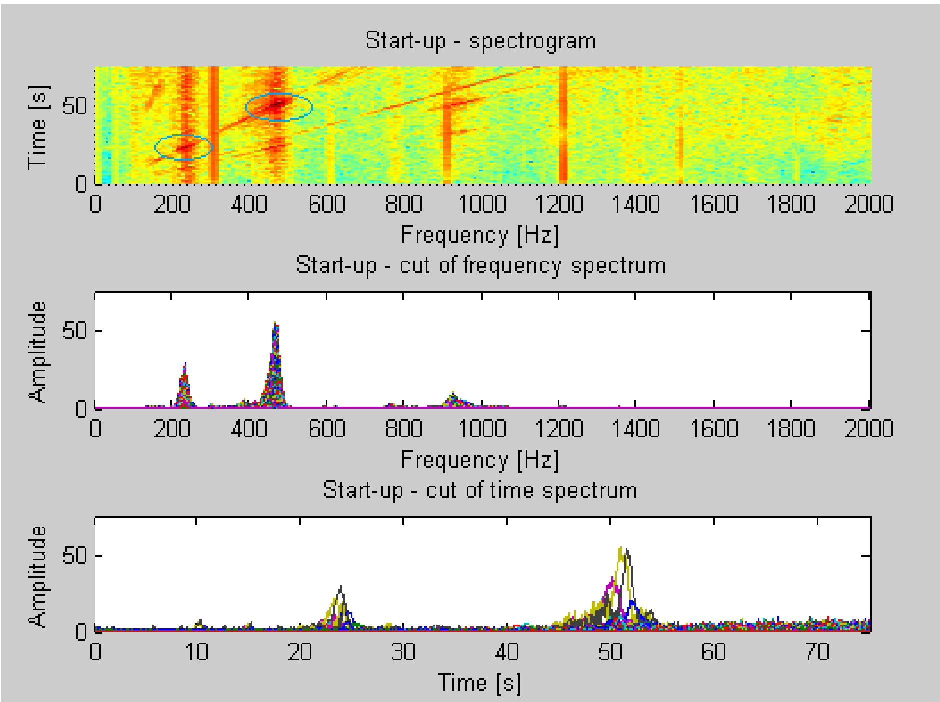

Fig. 3: Detection of resonance and natural frequency by means of STFT.

Displayed graphical contours investigated natural frequency and frequency aggregation that show appearance of resonance effect. From Figs. 3 and 4, we are able to investigate following parameters and their occurrence at specific frequency, time and RPM.

$$t = 23\ s \rightarrow 230\ Hz\ \rightarrow 517.8\ RPM\ \rightarrow 9.22\ order$$

$$t = 51\ s\ \rightarrow 470\ Hz\ \rightarrow 1031\ Hz\ \rightarrow 18.43\ order$$

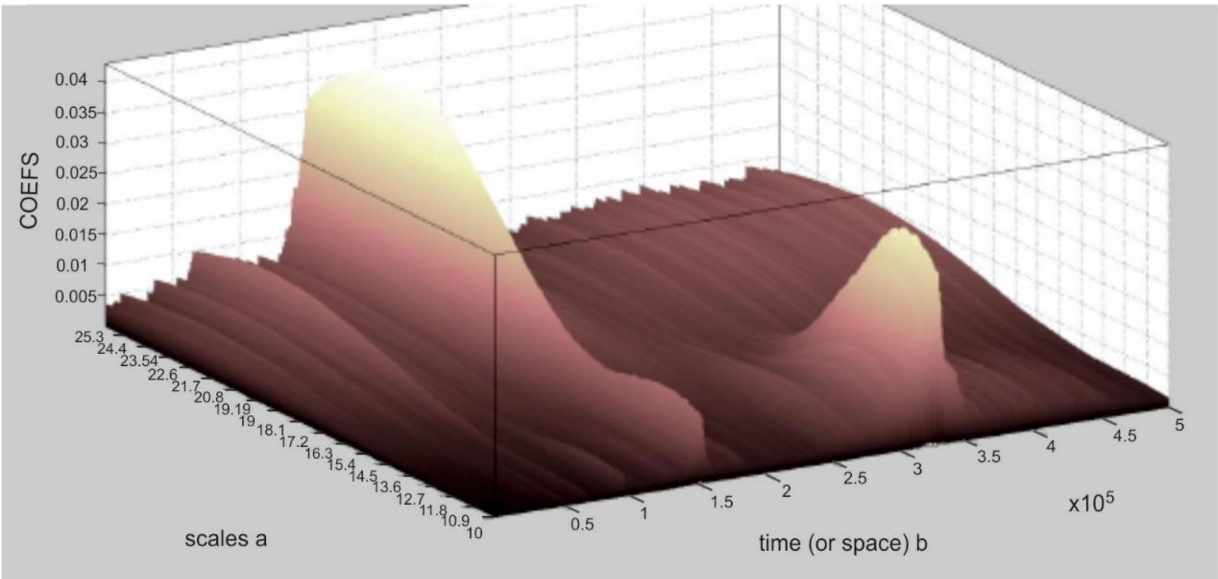

Fig. 4: Detection of resonance and natural frequency by means of Wavelet transformation.

5. Conclusion

STFT Method and Wavelet transform provide more extensive analysis options that are relevant to the processing the data of non-stationary modes (start-up). The most important advantage of the application of these mathematical methods is the detection of effects arising in complex installations oscillations in the time domain as well as in frequency domain. Algorithms for signal analysis method STFT, Wavelet transform (CWT) and graphical outputs were created in MATLAB R2014 user environment. The environment provides fairly wide range of graphic processing (color maps, 3D charts, graphical contours to coordinate frequency-amplitude and time-amplitude spectrum) (Sága, 2011). The purpose of the analysis was to find out events of oscillation (resonance identification, natural frequency) during ongoing measurements, i.e. during operation of mechanical object. We can assume that the results obtained by these methods will be in scale of necessary resolution, comparable and virtually the same.

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