Analysis of Vibrations of Bucket Wheel Excavator Schrs1320 During Mining Process

Jakub Gottvald
Head of department
VÍTKOVICE ÚAM a.s.

Presented paper deals with an evaluation of measuring of vibrations on a bucket wheel excavator (BWE) SchRs 1320 during mining. Vibrations were measured on the BWE's upper steel structure by using 28 accelerometers. Measured signals were associated with operating data from the BWE's central control computer. By connecting these two signal groups a complete set of valuable data was obtained. This data set was analyzed by time-frequency transforms. This paper shows results for three selected time periods. Results proved frequency changes in vibrations of upper steel structure of the BWE during moving in mining process.

Keywords: *Bucket wheel excavator, Natural frequency, Vibrations, Accelerometer, Fourier transform, Frequency, Amplitude, Measuring, Time-frequency transform.*

1. INTRODUCTION

All machines that are used for mineral mining especially bucket wheel excavators (BWEs) belong to extremely dynamically loaded structures. In these machines the digging forces are a dominant source of vibrations. Intensity and frequency of digging forces are dependent on the construction of bucket wheel and on the characteristic of overburden [1,2]. Digging forces are also dependent on the chosen method of mining, and there are differences between terrace and dropping cut methods. Important factors, which are most deserving of further analysis or measurements, can be identified by means of the sensitivity and statistical analysis, see, e.g. [3-6]. In practice the influence of the digging forces on steel structure of the BWE and on any of the significant components are frequently analysed. Critical nodes whose damage due to fatigue could be of fatal consequences are determined numerically and/or experimentally [7-10]. However, digging forces are not the only source of vibrations that could cause problems during operation. The BWEs are mechanisms, i.e. machineries, making different movements during mining process. These movements alone or in combination with digging forces could a be source of undesirable vibrations.

Presented paper deals with the analysis and measurement of vibrations at the BWE SchRs 1320 during mining process. The BWE SchRs 1320 was put into operation in 2006 and is operated at the opencast mine Doly Nástup Tušimice, Czech Republic. Since the very beginning of its operating process the BWE faced several problems with bucket wheel drive. During a very short operating time the failure of gearbox happened.

During the investigations on the causes of this failure several measurements and tests were made; the frequency changer of bucket wheel drive was identified as the main cause of the failure by the supplier of the gearbox. In the first instance as the possible solution the reduction of length of the cardan shafts between gearbox and motors was suggested, and subsequently it was also suggested to put the hydro couplings in front of the entrances to the gearbox. These changes lead to the reduction of vibrations and were accepted by the supplier of the gearbox, who consequently permitted its further operation. The outcome is that the frequency changer puts the motor in motion and then runs at nominal revolutions. However, above mentioned changes lead to the operating limitations of bucket wheel drive. The BWE SchRs 1320 has the bucket wheel drive which is able to work but with restrictions – e.g. the corrections of the revolutions of bucket wheel are not possible as required. In the contract the possibility of regulation of revolution speed of the bucket wheel in the interval of 50-120% nominal revolutions was specified; more over very slow revolutions during necessary cleaning process of buckets are impossible too. However, the owner naturally wants the BWE without any restrictions; this need was the main reason for activities focused on the correction of the bucket wheel drive. The presented paper deals with analysis of vibrations of the steel structure of the BWE SchRs 1320 especially of the bucket wheel boom part.

1.1 Introduction of BWE SchRs 1320

The BWE SchRs 1320 (in accurate description SchRs 1320/4x30, where 4x30 is the depth and height reach of the bucket wheel boom) is operated at the opencast mine Doly Nástup Tušimice, Czech Republic. The main supplier of the BWE was the PRODECO Inc. in cooperation with the German company Tryssen Krupp. The BWE was put into operation in 2006.

The BWE SchRs 1320 is conceived as an excavator with non-telescopic bucket wheel boom. Movement of the excavator is facilitated by crawlers. The theoretical

Received: June 2012, Accepted: October 2012
Correspondence to: Jakub Gottvald, Ph.D.
VÍTKOVICE ÚAM a.s, Ruská 2887/101, 706 02
Ostrava-Vítkovice, Czech Republic
E-mail: jakub@gottvald.eu

capacity of the excavator is 5500 m3 of overburden per hour. The excavator is approx. 100 m long and approx. 60 m high. Together with the loading unit and connecting bridge, it weighs 4193 tonnes. The diameter of the bucket wheel over buckets, which are 26, is 12 m.

An overall view of the BWE SchRs 1320 is presented in Figure 1.

Figure 1. Overall view of BWE SchRs 1320

2. MEASURING AT THE BWE SCHRS 1320

On the upper structure of the BWE 28 accelerometers were installed, for details see [11-13]. These accelerometers were installed on important parts of top structures of the excavator. Accelerometers were attached in triplets. Each triplet was able to log up signals at all of the three directions of oscillation. Measured data was stored using EMS DV devices. For the measuring, the sampling frequency 25 Hz was set.

In evaluation process of vibrations that were measured during operation it is very hard to determine retrospectively the correct movements of the BWE. This aspect was solved by measurement of the movements by the probes that are used for control of the BWE. In the controlling computer the logging of operating data was set so it was synchronized with signal from accelerometers. In the evaluations of vibrations during the mining process six general signals of movements were used - horizontal and vertical location of the bucket wheel boom, input power and revolutions of the bucket wheel motors, input power of motor used for horizontal rotation of the upper part of the BWE and overall movement of the BWE by undercarriage.

During two week measurement at the BWE SchRs 1320 very valuable data set was obtained. In presented paper, three selected time periods are analyzed, benefits of this analyses are shown and also signals measured by accelerometers A_06z and A_17y are presented. Accelerometer A_06z was situated in the right bearing of the bucket wheel shaft in vertical direction. Accelerometer A_17y was situated in the top of the inclined tower in horizontal direction.

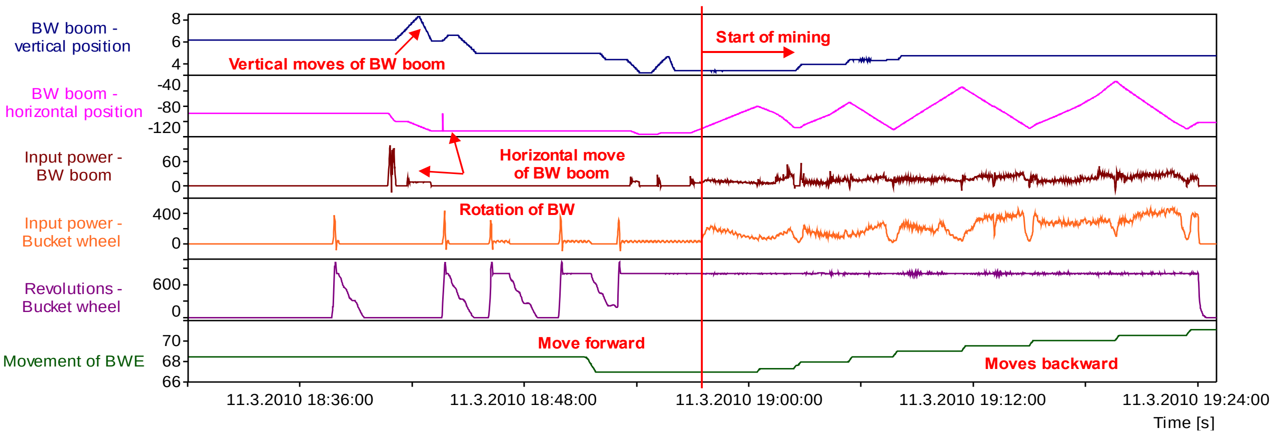

Figure 2. Courses of operating signals for selected time period no. 1

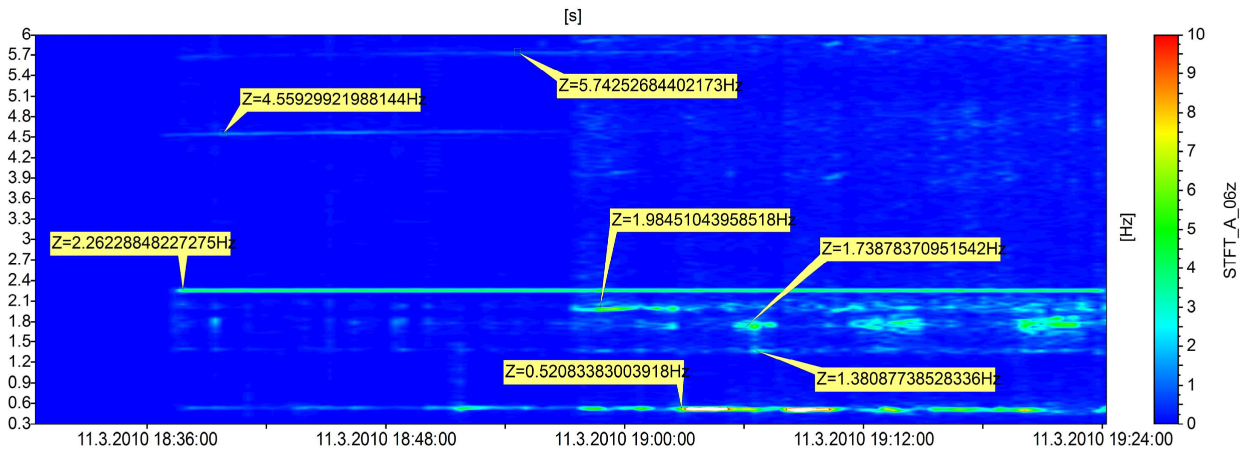

Figure 3. Time-frequency amplitude spectrum [mg], accelerometer A_06z, time period no. 1

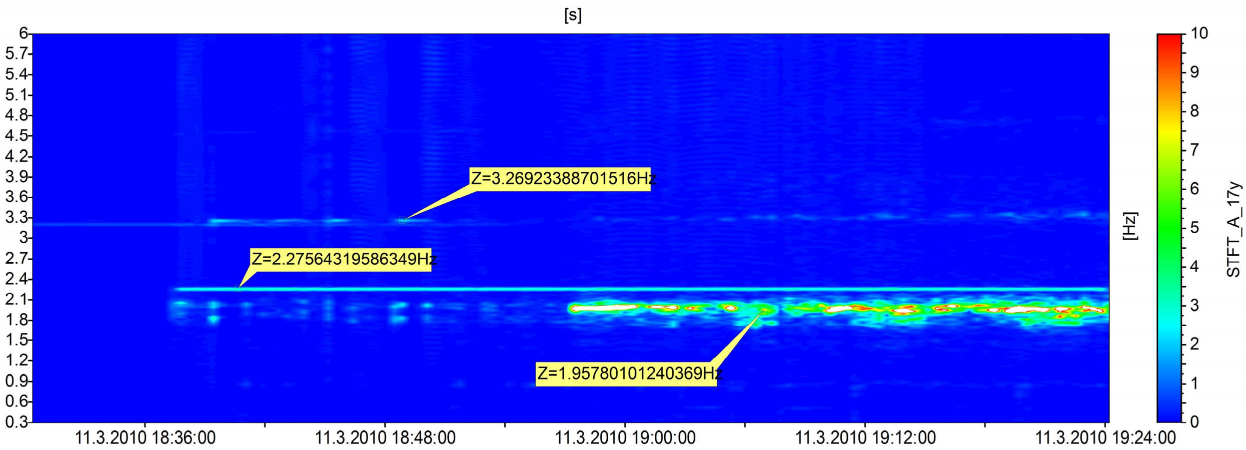

Figure 4. Time-frequency amplitude spectrum [mg], accelerometer A_17y, time period no. 1

2.1 Methods of signal analyses

For calculation of the frequency spectrums many kinds of transformations could be used. The best known and most widely used is the Fourier Transform (FT) and its modification of the Fast Fourier Transform (FFT). These types of transformations are particularly suitable for analyses of the stationary signals. It can also be used for analyses of non-stationary signals but we must be aware that information about time occurrence of the frequency spectrum peaks is lost by this procedure. For localization of the frequency spectrum peaks in time the Time-Frequency analyses methods must be used [12,14]. By Time-Frequency analyses we can analyze frequency spectrum as well as by classical frequency analyses. Its benefit is that we obtain additional information on time location of each of frequency peaks. Time-Frequency analyses are generally divided into linear and nonlinear types. In industry linear types are more used, especially the Short-Time Fourier Transform (STFT) [14,15] and the Wavelet Transform (WT) [14,15]. Both of these Time-Frequency transformations are included in program the FlexPro [15] that was used for analyses.

2.2 Selected time period no. 1

The selected time period shows the start of the mining process of the BWE, It is evident from time course of operations signals, see Figure 2. Before start of the mining the bucket wheel was rotated four times. After the first rotation of the bucket wheel two movements of the bucket wheel boom (up and down) were made. During the second lift, the bucket wheel boom had changed the horizontal position, too. Approximately in the middle of the selected time period the BWE started to mine. In Figure 3 results of STFT analyses for signal from accelerometer A_06z and in the Figure 4 the result for signal measured by accelerometer A_17y are plotted.

The results show that vibrations of the upper steel structure of the BWE started immediately after first movement of the bucket wheel. The size of amplitudes increased after the start of mining, especially when the bucket started to cut the overburden. In the results amplitude peaks at frequencies 0.52 Hz, 1.38 Hz, 1.70 Hz and 2.0 Hz are evident. Since the beginning of the movement of the bucket wheel the significant amplitude peak with strait base at frequency 2.26 Hz has appeared. It was caused by oil pump of gearbox of the bucket wheel.

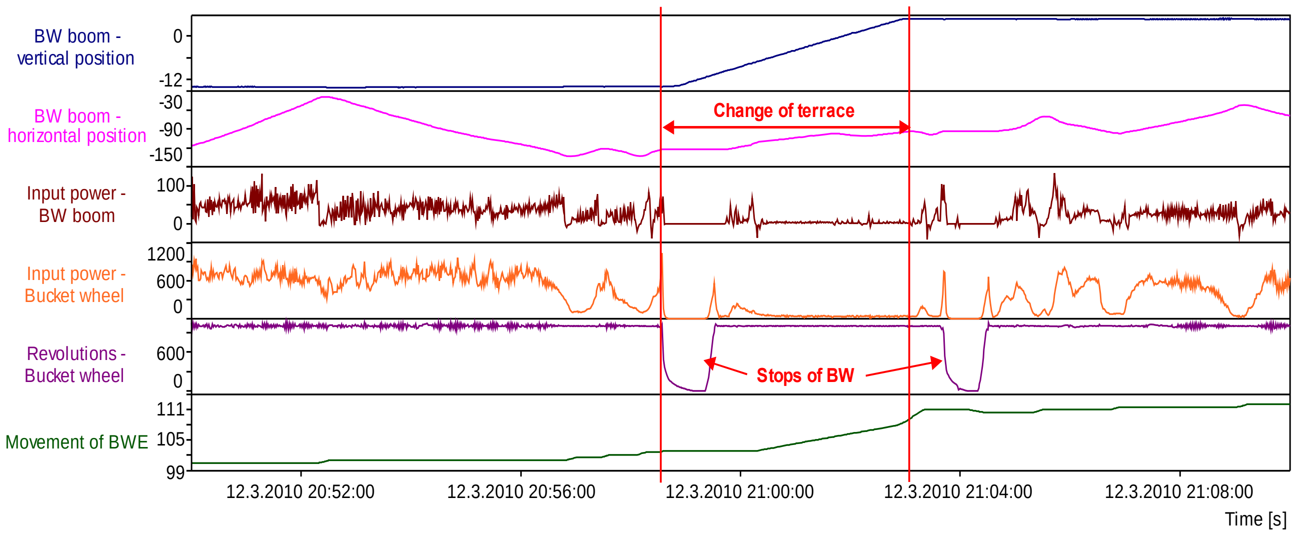

Figure 5. Courses of operating signals for selected time period no. 2

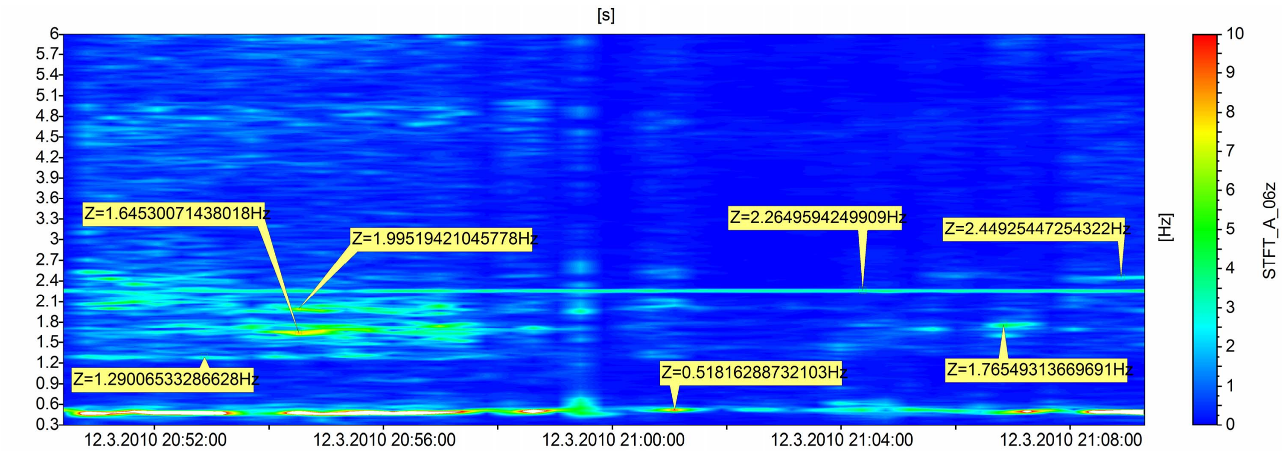

Figure 6. Time-frequency amplitude spectrum [mg], accelerometer A_06z, time period no. 2

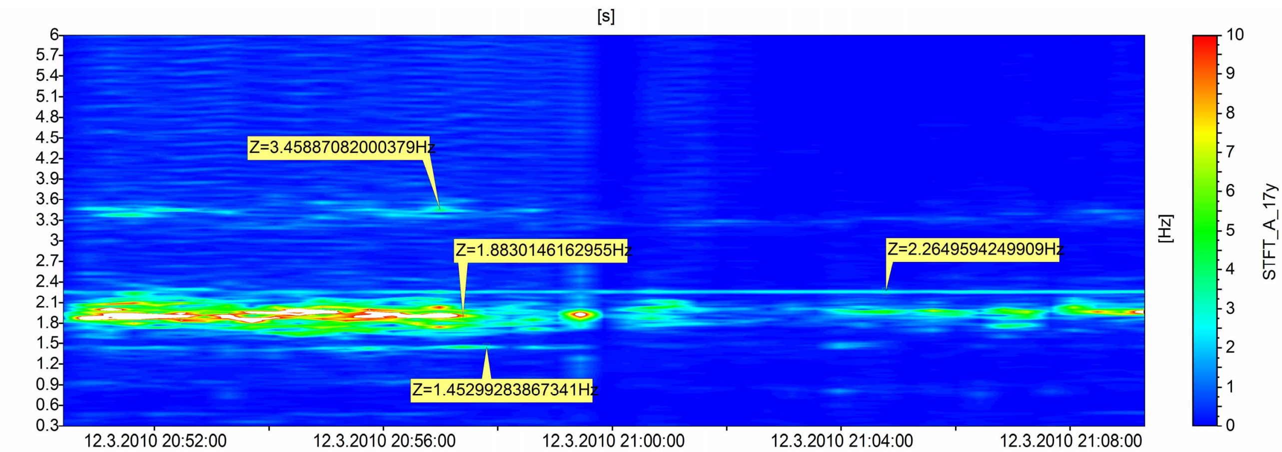

Figure 7. Time-frequency amplitude spectrum [mg], accelerometer A_17y, time period no. 2

2.3 Selected time period no. 2

This entry shows record during the change of terraces. The BWE mined at the bottom terrace and then it moved to the upper terrace. During the lifting movements of the bucket wheel boom the bucket wheel was stopped two times. The course of the operation signals are shown in Figure 2. In the Figure 6 the results of STFT analyses for signal from accelerometer A _06z and in the Figure 7 the result for signal measured by accelerometer A_17y are plotted.

From the spectra of amplitudes shown in the Figures 6 and 7, it is clear that start of the mining at new terrace did not cause as much response on the structure of the BWE as at the end of mining on the previous terrace. This was caused by mining of very low terraces which is connected with reduced need of the input power at the bucket wheel motor drive. On the results from the accelerometer A_06z frequency amplitudes peaks at frequency 1.65 Hz and 2.00 Hz during change of horizontal movement of the bucket wheel boom in the terraces are localized, see Figure 6. At the moment when a terrace was changed and the bucket wheel drive to mining face very height increase of input power at bucket wheel motor drive occurred, see Figure 5. In the results from accelerometer A_17x there are significant amplitude peaks at frequency band around 1.9 Hz, see Figure 7. Width of this frequency band depends on the character of mining process; see comparison between the end of the results from old terraces and results from the new one. Throughout all the measurement the oil pump of gearbox of the bucket wheel was in progress, see significant amplitude peak at frequency 2.26 Hz.

2.4 Selected time period no. 3

During this measurement the change of terraces has also occurred, but this time it was the change from up to down, and it means different movement of the BWE (reversing). The course of the operating data is plotted in the Figure 8. In the Figure 9 results of STFT analyses for signal from accelerometer A _06z are plotted and the Figure 10 shows the result for the signal measured by accelerometer A_17y.

From calculated results in the Figure 10 (accelerometer A_17y) and particularly from the Figure 9 (accelerometer A_06z) harmonic amplitudes in frequency spectrum are evident; the highest amplitude is at frequency 3.68 Hz. At the end of the bucket wheel boom (accelerometer A_06z) amplitudes peaks at frequencies 0.52 Hz, 1.30 Hz, 1.74 Hz, 2.00 Hz, 2.43 Hz are significant and there is also a strong peak of constant amplitude at frequency 2.26 Hz. These frequencies are evident during mining and are less significant during change of terraces. Very important is the shift of a value of the first natural frequency from 0.52 Hz to 0.49 Hz (accelerometer A_06z). It is caused by change of position of the bucket wheel boom.

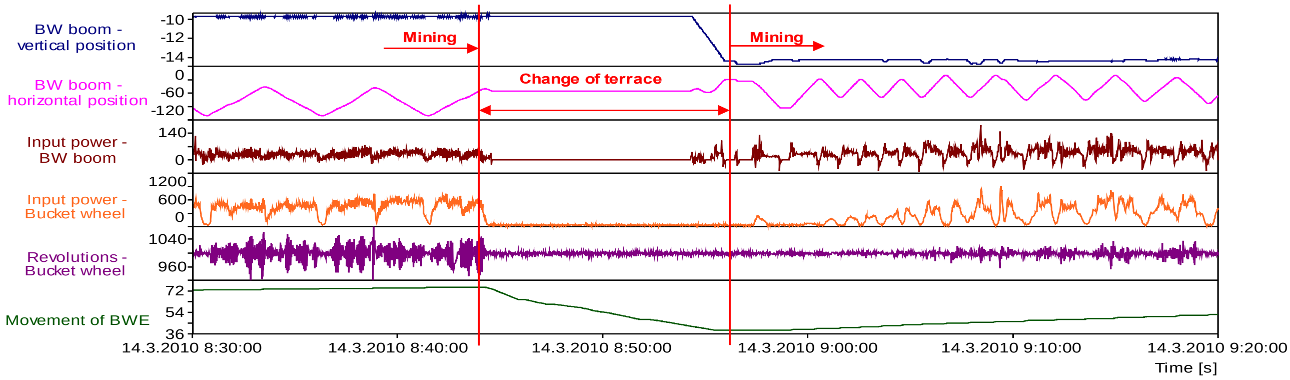

Figure 8. Courses of operating signals for selected time period no. 3

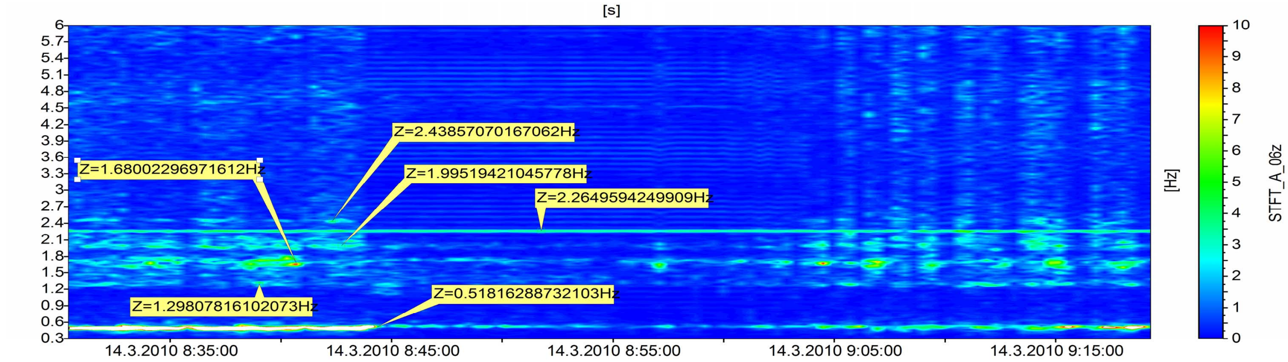

Figure 9. Time-frequency amplitude spectrum [mg], accelerometer A_06z, time period no. 3

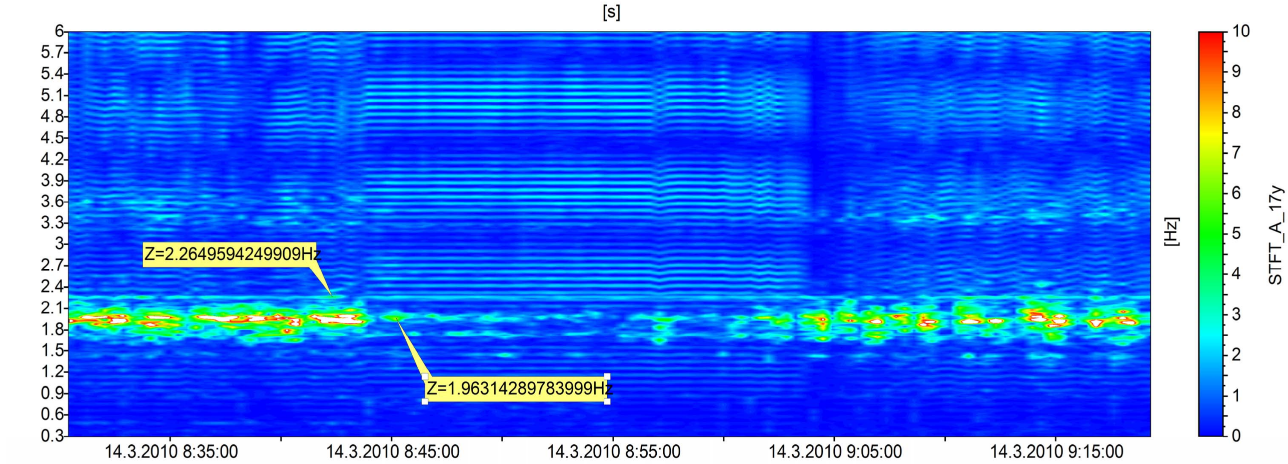

Figure 10. Time-frequency amplitude spectrum [mg], accelerometer A_17y, time period no. 3

Accelerometer A_17y which was located at the top of the inclined tower in horizontal direction has different amplitude spectrum. There are significant amplitudes in the frequency band from 1.63 Hz to 2.12 Hz. During the process of terrace change this frequency band was changed at two amplitudes at frequencies 1.74 Hz and 1.96 Hz. Oil pump of gearbox of the bucket wheel was in progress during the whole measurement, see amplitude at frequency 2.26 Hz.

3. CONCLUSION

While analyzing dynamical properties of the BWE SchRs 1320 several measurements were made. Several interesting situations were analyzed, such as moves of some parts of the BWE, the start and the end of mining or its interruption. The experiment of special sequence of movements by the BWE was made. A series of movements with bucket wheel boom, the whole bucket wheel, etc. and their influence on vibration were analyzed. Measurement of the whole mining process of 20.5 m high block of overburden that was mined by terrace cutting method in four terraces was made. The height of the block roughly corresponds to the height of the joint of the bucket wheel boom; it means that the bucket wheel boom was approximately in its horizontal position. It was evaluated that the first natural frequency of the BWE SchRs 1320 in the first terrace is 0.504 Hz, in the second terrace it is 0.495 Hz, in the third terrace it is 0.483 Hz, and in the fourth terrace it is 0.469 Hz [16]. There was a declining trend in the first natural frequency. The difference between first and fourth terrace was 0.035 Hz. The comparison of natural frequencies during mining with natural frequencies that was measured experimentally [11, 13] shows that effects of digging forces cause the decrease of value of the first natural frequency. In measuring of natural frequency the value 0.545 Hz (0.6 Hz for bucket wheel in interaction with overburden) was found out [11], but during mining the values of the first natural frequency in the terraces ranged from 0.5 to 0.46 Hz [12, 14]. These trends are evident in the time-frequency spectra that are described in the presented paper.

ACKNOWLEDGMENT

The author gratefully acknowledges the financial support provided by the Ministry of Industry and Trade of the Czech Republic within the project FR-TI1/086.

REFERENCES

[1] Schlecht, B.: *Simulation of the Bucket Wheel Drive of a Compact Bucket Wheel Excavator*, Krupp Fördertechnik GmbH, p. 11., 1999.

[2] Schlecht, B., Wünsch, D., Deckers, J. and Holtmann, M.: *Experimental analysis of digging force on tooth of compact bucket wheel excavator by using of piezoelectric probe*, Technishe Universitat Dresden, 1999.

[3] Gottvald, J. and Kala, Z.: Sensitivity analysis of tangential digging forces of the bucket wheel excavator SchRs 1320 for different terraces, Journal of Civil Engineering and Management, Vol. 18, No. 5, pp. 609-620, 2012.

[4] Kala, Z.: Geometrically non-linear finite element reliability analysis of steel plane frames with initial imperfections, Journal of Civil Engineering and Management, Vol. 18, No. 1, pp. 81-90, 2012.

[5] Kala, Z.: Influence of partial safety factors on design reliability of steel structures - Probability and fuzzy probability assessments, Journal of Civil Engineering and Management, Vol. 13, No. 4, pp. 291-296, 2007.

[6] Strauss, A., Kala, Z., Bergmeister, K., Hoffmann, S. and Novák, D.: The object of this contribution is the comparison of the statistical characteristics of yield strength, ultimate strength and ductility of Austrian and Czech steels [Technologische eigenschaften von stählen im europäischen vergleich], Stahlbau, Vol. 75, No. 1, pp. 55-60, 2006.

[7] Bošnjak, S., Petković, Z., Zrnić, N., Simić, G. and Simonović, A.: Cracks, repair and reconstruction of bucket wheel excavator slewing platform, Engineering Failure Analysis, Vol. 16, No 5, pp. 1631-1642, 2009.

[8] Rusinski, E., Harnatkiewicz, P., Kowalczyk, M. and Moczko, P.: Examination of the Causes of a Bucket Wheel Fracture in a Bucket Wheel Excavator, Engineering Failure Analysis, Vol. 17, No 6, pp. 1300–1312, 2010.

[9] Bošnjak, S., Arsić, M., Zrnić, N., Rakin, M. and Pantelic, M.: 2011. Bucket wheel excavator integrity assessment of the bucket wheel boom tie-rod welded joint, Engineering Failure Analysis, Vol. 18, No 1, pp. 212-222, 2011.

[10] Bošnjak, S., Petković, Z., Zrnić, N., Pantelić, M. and Obradovic, A.: Failure analysis and redesign of the bucket wheel excavator two-wheel bogie, Engineering Failure Analysis Vol. 17, No. 2, pp. 473–485, 2010.

[11] Gottvald, J.: The calculation and measurement of the natural frequencies of the bucket wheel excavator SchRs 1320/4x30, Transport, Vol. 25, No 3, pp. 269–277, 2010.

[12] Gottvald, J.: *Experimental and probabilistic analysis of operational reliability of the bucket wheel excavator SchRs 1320/4x30* [*Experimentální a pravděpodobnostní analýza provozní spolehlivosti kolesového rypadla SchRs 1320/4x30*], Ph.D. thesis, Brno University of Technology, Brno, p. 205, 2011, (in Czech).

[13] Gottvald, J.: Measuring and comparison of natural frequencies of bucket wheel excavators SchRs 1320 and K 2000, in: *Proceeding of the 4th WSEAS international conference on engineering mechanics, structures, engineering geology (EMESEG '11),* 14-17.07.2011, Corfu Island (Greece), pp. 335-340.

[14] Steven, W. S.: *The Scientist and Engineer's Guide to Digital Signal Processing*, California Technical Pub, 1999.

[16] Gottvald, J.: Analysis of steel structure vibrations of the bucket wheel excavator SchRs 1320, in: *17th International conference Engineering mechanics*, 09-12.5.2011, Svratka, Czech Republic, pp.159-162.

[15] FlexPro 7 - Program manual. Weisang GbmH, 2007.

АНАЛИЗА ВИБРАЦИЈА РОТОРНОГ БАГЕРА SchRs 1320 ТОКОМ ПРОЦЕСА КОПАЊА

Јакуб Готвалд

Изложени рад бави се мерењем вибрација роторног багера SchRs 1320 током копања. Вибрације су мерене на горњој строју помоћу 28 акцелерометара. Измерени сигнали су повезани са оперативним подацима централног контролног компјутера. Повезујући ове две групе сигнала добијен је важан сет података. Ови подаци су анализирани коришћењем временско фреквентне трансформације. У раду су приказани резултати за три изабрана временска периода. Резултати потврђују промене у вибрацијама горњег строја роторног багера током померања током процеса копања.