THE PARAMETER CORRELATION OF ACOUSTIC EMISSION AND HIGH-FREQUENCY VIBRATIONS IN THE ASSESSMENT PROCESS OF THE OPERATING STATE OF THE TECHNICAL SYSTEM

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Abstract: The article describes application of selected methods of technical diagnostics for assessing the operating status of precision gearboxes. Within the confines of experimental measurements in the field of physical metallurgy materials of diagnosed system were being examined while taking into account the process of degradation of material properties during operation of monitored gearboxes. Measurements and collecting of dynamic data were realized on 4 selected gearboxes where a high-frequency vibrations and acoustic emission (noise) measurements were carried out. Retrieved values were subsequently used for mutual correlation and verification of applied methods. Results of both selected methods underlined unsatisfactory operation status with 3 inspected gearboxes. Measured values were identified as being above suggested caution limit of Alarm 2, representing a level of danger.

Key words: Technical Diagnostics, Vibrodiagnostics, Analysis of Dynamic Signal

1. INTRODUCTION

The most important role of technical diagnostics lies in predicting the technical condition of the system being assessed. One of the objectives of technical diagnostics is predicting of duration of flawless operation, i.e. time interval between observed moment up to occurrence of failure. The failure prediction is based on identification of deterioration in the condition of assessed systems and determining the moment when it is necessary to implement appropriate measures in order to prevent failures and undesired damage (Janoušek et al, 1988; Valent et al., 2010; Panda and Prislupčák, 2014).

Basic tasks of diagnostics is to determine the diagnosis characterizing the technical state of the object in terms of failures and this diagnosis must be usable for optimizing the servicing (maintenance) actions in order to bring the object to normal state. Monitored features of diagnosed object are vital for the success of the diagnostic system. One of the most important properties is diagnosability, i. e, feature that allows you to obtain information about the technical condition using diagnostic tools; in other words it presents the capacity of the object for the use of diagnostic equipment. The machine is sufficiently diagnosable if it is possible to perform all diagnostic tasks easily with required accuracy and, if possible, low cost (Valent et al., 2010; Hreha et al., 2010; Michalik et al., 2014; Šebo et al., 2013).

In the process of technical diagnosis variety of techniques is applied to diagnose machines but it often happens that the measurements are not interpreted or interpretation is not correct. Within the frame of vibration diagnostics there are occurrences of realizing the very collecting and recording of the vibrations signals while ignoring the force and energy that causes fatigue damage to machine parts and thusly shortens their lifespan.

It means that twice the force shortens durability of the bearings to 1/8 of technical serviceability and device's lifespan is reduced from 5 – 10 years to only several months. Bearing diagnostics is a very demanding field and if technical diagnostician relies only on "their" method, the results of their work can even be fatal. Bearing damage can be caused by unsuiTab. lubricant, contaminated lubricant, water, excessive force, oxidation and degradation of the lubricant additives. The human factor can cause that bearing is installed with a larger overlap, overheated during installation or it is over-lubricated, insufficiently lubricated or without oil. These difficulties can shorten the bearing lifespan by a few hours up to several months (Valent et al., 2010; Šebo et al., 2013; Stejskal et al., 2013; Šoltésová and Baron, 2013; Jurko et al., 2011).

Based on cooperation of our department with practice the demand arose for accurate assessment of the operating condition of gearboxes. Four selected gearboxes were analyzed. In the context of diagnostic it was applied measurement of high-frequency vibration and acoustic emission. The measured values were used for the cross-correlation and verification of selected methods.

2. DESCRIPTION OF THE MEASURING - CHARACTERISTICS OF THE MACHINES AND MEASURING METHODS

In the process of diagnostic activities for the purpose of vibration measurement, process data collection and subsequent analysis the following diagnostics systems were used:
− the frequency analyzer and Data Collector Microlog GX,
− the software interface of Aptitude Analyst,
− vibration sensor, accelerometer Wilcoxon Research Model

SKF786M, sensitivity 100 mV/g, frequency range from 1 to 20 000 Hz.

Used measuring method based on recommendations of the technical standard STN ISO 10816-3 – Mechanical oscillation. Evaluation of machine oscillation by measuring on non-rotating parts of machine.

For purpose of vibration assessment in the low frequency area the following were applied:

− The measurement method Velocity (vibration velocity), unit mm/s, RMS detection.
− According to the recommendations of ISO 10816-3, FFT (Fast Fourier Transform) frequency spectrum for the area from 10 to 800 Hz.
− The measurement method Enveloping Acceleration (method of measuring the vibration acceleration in the high frequency range to 10 - 20 kHz through which assessment is carried out in particular for the state of the rolling bearings and gear ratio), unit Eg, detection of PtP, the frequency area from 50 to 1000 Hz, FFT spectrum and time record.

For the assessment of vibration in the high-frequency area the following methods were used:

− The measurement method Acceleration (vibration accelera-tion), unit g, detection of PtP, frequency range up to 16 kHz, the FFT spectrum and time record.

− The measurement method Acceleration Enveloping, unit Eg, detection of PTP, Frequency range up to 10 kHz to 20 kHz, the FFT spectrum and time.

Diagnostic methods for the assessment of acoustic emission and ultrasound:

− The measurement method See (Spectral Emitted Energy) – acoustic emissions (SKF), a unit See, detection of PtP, frequency range up to 600 kHz, the FFT spectrum and time record.
− The measurement method HFD – High Frequency detection method (SKF), analysis of vibration (acceleration) in frequencies 40 kHz.
− Method for assessment of the state of lubrication, resistance of the oil film, metallic contact, sticking, abrasion of contact surfaces (bearings and gear).

3. RECORDING AND RUNNING OF OPERATING PARAMETERS - REALIZATION OF THE EXPERIMENTAL MEASUREMENTS

Tab. 1 contains a summary of the measured values of the ex-posure of noise and vibrations of the individual gearboxes marked A, B, C, D.

Tab. 1. Measured exposure values for noise and vibrations of gearboxes A, B, C, D

Gearbox	HF vibrations - oscillations			Sound - noise			Evaluation
	Acc	Acc	EnvAcc	LAeq	LASmax	LAImax	
	[g]	[g]	[gE]	[dB]	[dB]	[dB]	
	To 20 kHz	Zone 1 - 6 kHz	To 10 kHz				
A	8.09	6.87	3.67	79.5	81.0	84.6	A2
B	5.30	4.49	2.45	73.6	74.7	78.0	A2
C	4.43	3.07	1.58	72.5	73.8	75.5	A2
D	3.20	1.37	0.92	72.4	73.5	74.6	SUITAB.
ALARM 1 (A1)	3.30	2.20	1.00	-	-	-	
ALARM 2 (A2)	4.30	3.00	1.50	75.0	75.0	75.0	

Explanatory notes: Acc – acceleration of vibration displacement, EnvAcc – envelope of vibration acceleration, Laeq – value of the equivalent level of acous-tic pressure A, LASmax – the maximum level of acoustic pressure using the weighting filter type A and the time constant "Slow", LAImax – the maximum level of acoustic pressure using the weighting filter type A and the time constant "Impulse".

The measured acceleration values were obtained by diagnos-tic system with the application of accelerometer Wilcoxon Re-search, SKF786M in cooperation with the PorTab. Data Collec-tor/FFT Analyzer SKF Microlog Analyzer (Fig. 3). The gearboxes were measured at one measuring point (acceleration).

The values of alarm levels (primarily for noise limits, sound pressure, acoustic emission and high frequency acceleration) are determined by the following ways:

− by agreement between a supplier (manufacturer) and custom-ers,
− when the signal increase over 200% compared to the refer-ence (agreed) level measured on the normal product quality and design,
− by comparing the dynamic characteristics of competing manu-facturers - suppliers), respectively by comparing the measured

values with the normal level of the same products in the local market.

In the specific case of defined alarm set points were based on an analysis of signal levels of 95% of the measured values of controlled amount of the same types of mechanisms (see. Tab. 1).

From the diagram of the measured values of the gearbox "A" (Fig. 4) it is seen that the value of the frequency about 2700 Hz achieved the level of noise 81 dB, respectively 84,6 dB.

FFT spectrum of a vibration signal confirmed the statement as with value about 2700 Hz measured signal value was: EnvAcc – 3.67 (gE), Acc – 6.87 (g), Acc – 8.09 (g). Time record of signal points to the unsatisfactory operating condition of the gearbox (Fig. 5). In both cases the measured values are set above the limit of alarm A2 (see Tab. 1).

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Fig. 1. The sound pressure measurement

Fig. 2. The contactless measuring of vibration by the laser vibrometer

Fig. 3. Accelerometer model Wilcoxon Research, SKF786M and PorTab. Data Collector/FFT Analyzer SKF Microlog Analyzer
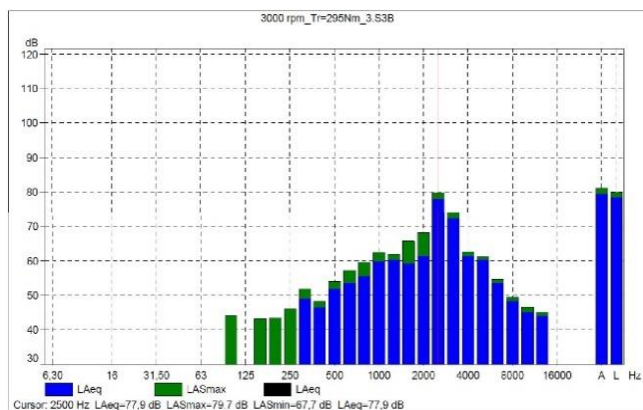
Fig. 4. Graphic record of acoustic emission for gearbox "A"
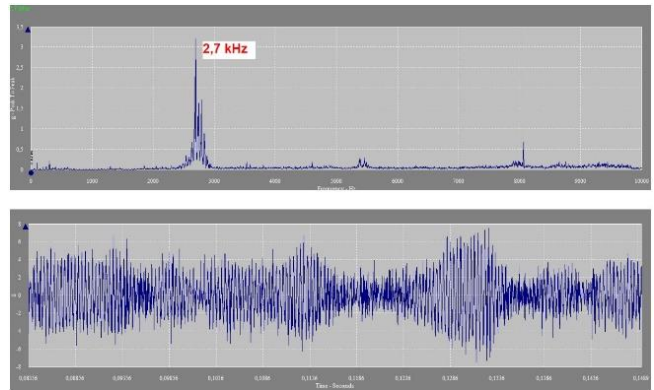
Fig. 5. FFT spectrum and recording TIME of gearbox „A"

In the case of the gearbox marked by the symbol "B" it is possible to record the state from the diagram when the vibration value about 4000 Hz is equal to the noise level of 74,7 dB and 78 dB (Fig. 6).
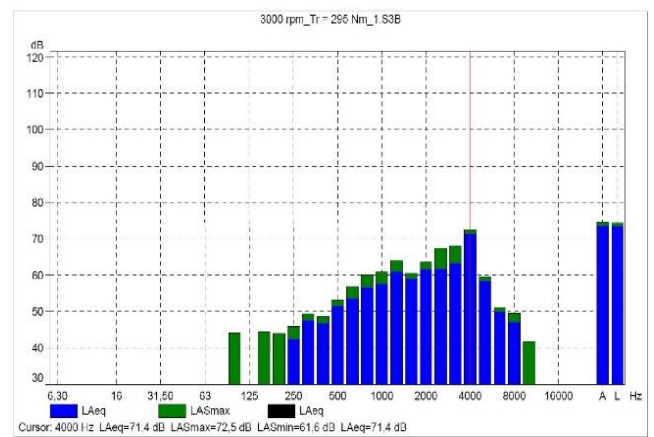

Fig. 6. The graphic record of acoustic emission for gearbox "B"

FFT spectrum of a vibration signal confirms the state where with value about 4200 Hz the measured signal value was: EnvAcc – 2.45 (gE), Acc – 4.49 (g), Acc – 5.30 (g). Time record of signal points to the unsatisfactory operating condition of the gearbox "B" (Fig. 7). In both cases the measured values are set above the limit of alarm A2.
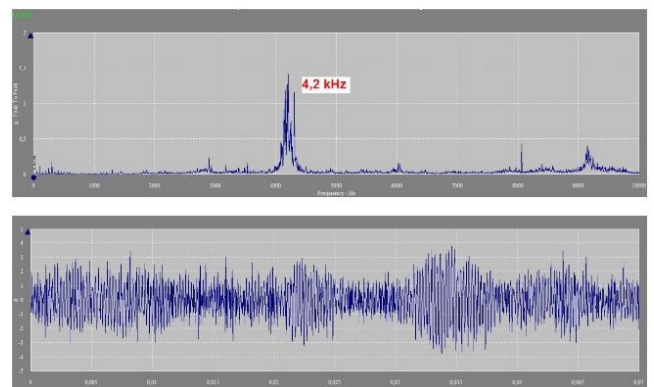

Fig. 7. FFT spectrum and recording TIME of gearbox „B"

For the third case – gearbox "C" in the vibration value about 4000 Hz had a vibration sound emission moving at the level of 73.8 and 75.5 dB (Fig. 8). FFT spectrum of a vibration signal confirmed that with value around 4150 Hz the measured signals value was: EnvAcc – 1.58 (gE), Acc – 3.07 (g), Acc – 4.43 (g). Time record of signal points to the unsatisfactory operating condition of the gearbox "C" (Fig. 9). In both cases the measured values are set above the limit of alarm A2.
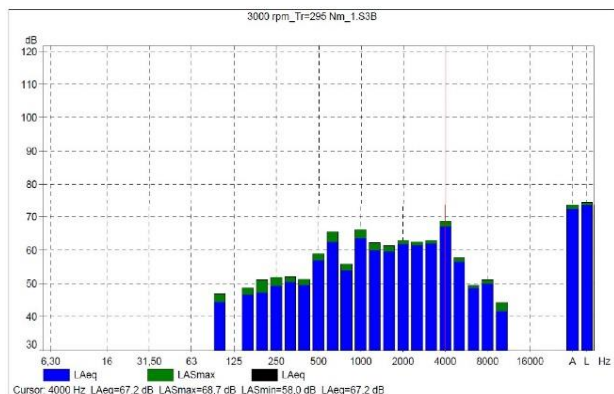

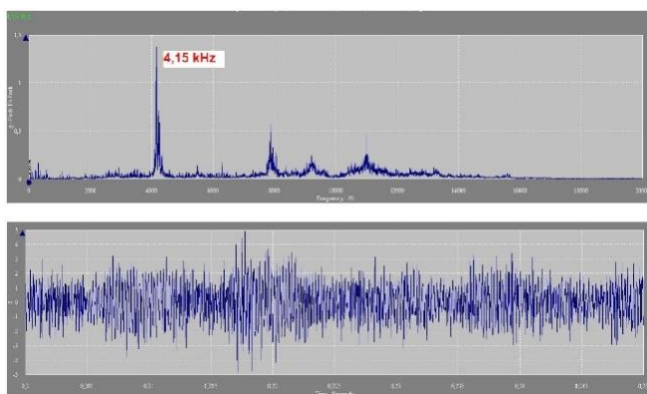**Fig. 8.** The graphic record of acoustic emission for gearbox "C"

Fig. 9. FFT spectrum and recording TIME of gearbox „C"

In the case of the last gearbox marked by the symbol "D" was recorded a state where the all zones were located below level of 70 dB without dominant frequencies across the whole monitored zone.
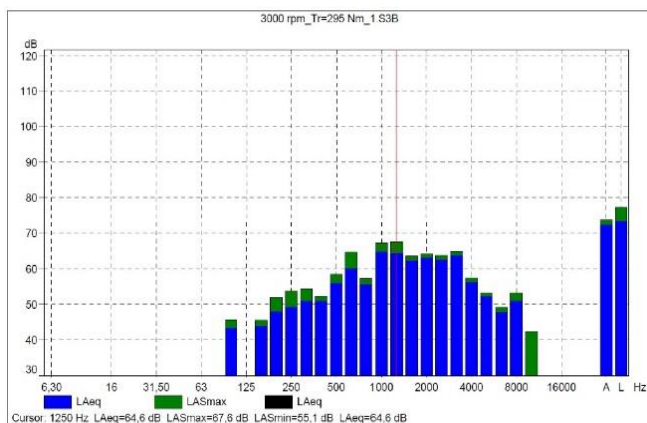

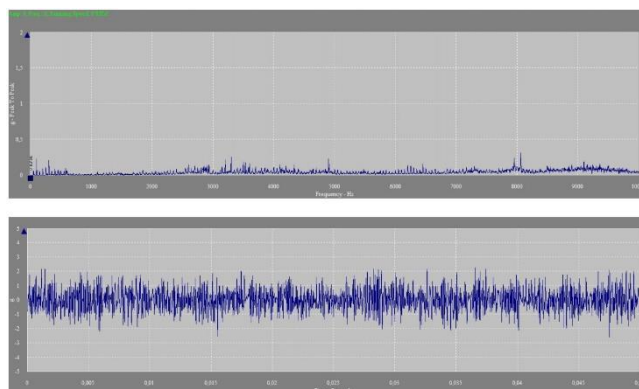**Fig. 10.** Graphic record of acoustic emission for gearbox "D"

Fig. 11. FFT spectrum and recording TIME of gearbox „D"

FFT spectrum of the vibration signal also confirms that within measurement area there is not a state of increased signal. The measured signal value was: EnvAcc – 0,92 (gE), Acc – 1,37 (g), Acc – 3,20 (g). Time record points to the satisfactory operating condition of the gearbox (Fig. 11). The measured values of both cases are within the defined limits, i.e. condition is satisfactory.

4. CONCLUSION

Noise and vibrations are closely related since in many cases the oscillating bodies are the cause of secondarily created noise and vice versa - air-transmitted acoustic energy can create interfering oscillation of constructions, worsening of workplace conditions etc. (Jurko et al., 2010; Dobránsky et al., 2015; Balthazar et al., 2013). The causes of vibration in technical practice are alternate forces that arise from the clearance and inaccuracies in rotating movements of machines, in vehicles movement and their parts, at work with the various machine tools, etc. Primary task of vibration diagnostics is early identification of moment of required maintenance or possibly changing the segment in assessed system before end of its working life. This type of diagnostics increases security, reliability and durability, the period between two repairs respectively. Finally, thereby reducing maintenance costs (Warminski et al., 2013; Hyung-Deok and Hun Lee, 2014; Wereley and Meinhart, 2010; Gallagher et al., 2012).

In respect to case of diagnostics of assessed precision gearboxes described in the article it is possible, based on realized measurements and analysis of dynamic signal by means of correlation of two methods, to state the following conclusion:
- operating state of gearboxes "A", "B" and "C" is unsatisfactory. The measured values are identified above the recommended limit of warning Alarm 2 (A2 – danger),
- gearbox "D" is in satisfactory working condition for all measured parameters and measurement methods.

After the realized repair of gearboxes "A" to "C" it is recommended to re-diagnose their operating status by measuring high-frequency vibrations. Consequently it is desirable, by measuring the microgeometry of contact surfaces, to assign the measured value of high dynamic signal for specific gearbox component, and define its eventual production inaccuracy (Asiri, 2007).

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