Method of defining diagnostic features to monitor the condition of the belt conveyor gearbox with the use of the legged inspection robot

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Abstract. This paper presents the results of constructing the inspection robot serving as a tool to define the conditions of technical infrastructure in deep mine. The project has been conducted as the part of the European "THING - subTerranean Haptic INvestiGator" project. The challenge of managing the dispersed deep mine machine park in the conveyor transport network has been discussed in the paper. One of the functions of the inspection is to evaluate the technical condition of the conveyor gearbox. Thus, the haptic robot leg has been designed to perform non-invasive vibration measurements on the gearbox housing. The inspection robot has been designed to consequently perform the necessary monitoring processes currently performed by human, which proves to be troublesome in the mining industry worldwide. The aim of the paper is to suggest the complete method of collecting field measurements and defining diagnostic features based on time-frequency analysis. Such an approach would facilitate full mobility and automatization of defining diagnostic features process with the robot, what is crucial in the harsh mining conditions.

Keywords: Inspection Robot, Deep Mine, Belt Conveyor, Gearbox, Condition Monitoring

1 Introduction

Belt conveyors which transport material are subject to numerous adverse incidents resulting from faulty construction, inappropriate selection of material properties, faulty assembly or incorrect exploitation. Such incidents, leading to breakdowns or repairs of the machines, generate substantial additional costs [1,2]. Therefore, in order to enhance the performance of the belt conveyor transportation system, the servicing costs are considered to be more important than the costs of initial investments. The shift towards the quality approach to the issues of exploiting belt conveyors might be observed. This change is aided by the constant development of measurement techniques in technical diagnostics and of methods and tools supporting the exploitation decision process [3,4]. SCADA software implemented for the daily operation provides the important data on mining performance. However, considering technical diagnostics, the software analyzes current or temperature data, which are insufficient for the complete insight into technical condition of vibrating parts, such as gearbox, bearing or drum. Commonly implemented SCADA software is limited to signal acquisition and raw data visualization [5,6,7]. Large mining enterprises often face difficulties in interpreting raw signals because of multiple stoppages and complexity of monitored processes [8]. More advanced online conveyor monitoring systems are expensive and arduous to maintain, taking into account the number of objects (>200), the spatial dispersion of machines (up to >100 km^2) and harsh environmental conditions in mines (temperature, dust, humidity, salinity). Therefore, advanced systems are implemented only at specific and critical locations.

The "THING- subTerranean Haptic INvestiGator" project has been initiated to respond to the expectations of contemporary users of belt conveyors. The project covers the construction of inspection robot used for evaluating the machine condition and the technical infrastructure of deep mines. It has been assumed that the inspection robot will take over the necessary monitoring processes currently performed by human (for example operating the conveyor). The robot might prove to be the indispensable tool particularly in harsh environmental conditions in deep mines which are subject to temperature and gaseous hazards. Considering harsh mining conditions, the crucial goal of the project is to ensure the proper robot's perception in terms of defining material and road surface (condition evaluation, location, mapping, identification of the environment in which the robot operates) [10,11] (see Fig. 1).

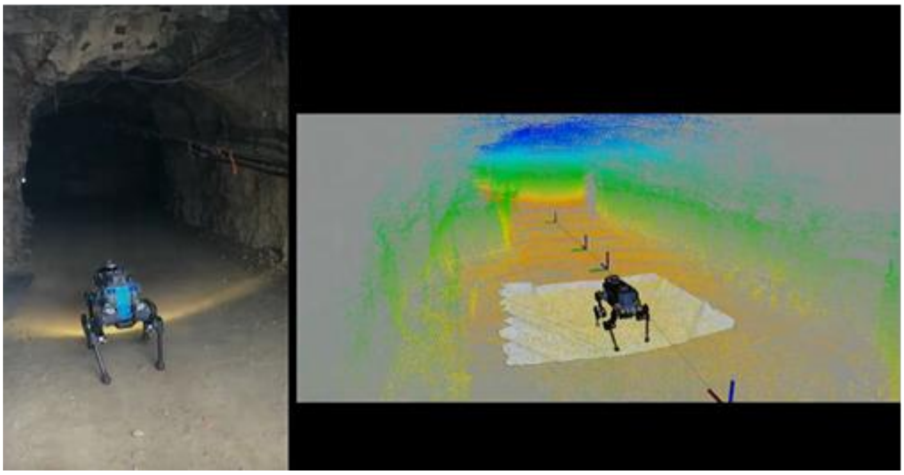

Fig. 1. Functional testing of robot in the tunnel (left), visualization depicting mapping of the passage while the robot moves in the tunnel (right).

The main focus of the inspection mission concerns the methodology of vibration measurements on the belt conveyor gearbox and of defining diagnostic features. Obtaining the measurements of vibration signal, its processing, further analysis and concluding on the features of vibration signal are inevitable to properly evaluate the condition. The simplest example of concluding follows: *if* **value of a feature** *is greater* *than* **alarming level,** *apply* **alarm status**; *if not, apply* **correct status**. Indeed, ongoing tracking of the level of diagnostic features can be used for estimation of residual lifetime of gearbox in the future. For better comprehension, Fig. 2 shows the general idea of determining decision thresholds.

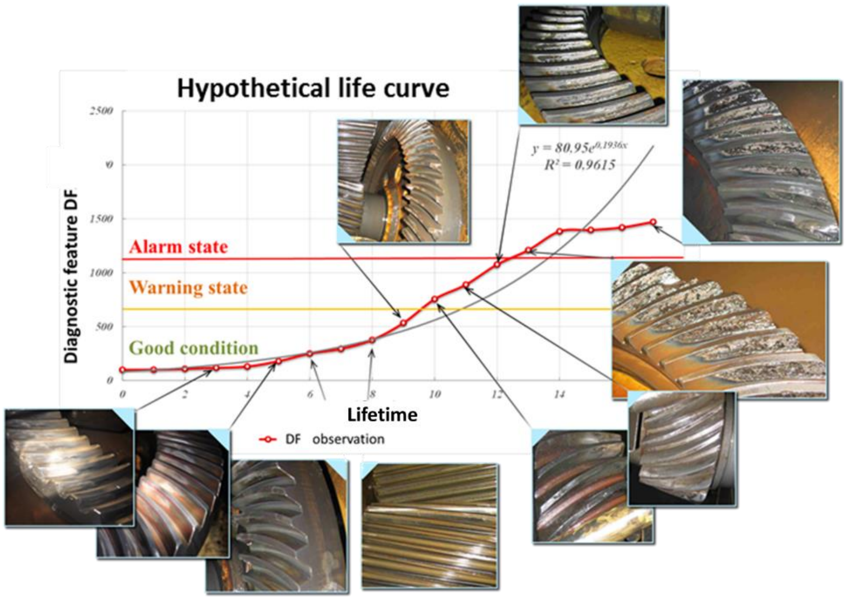

Fig. 2. Hypothetical life curve based on proposed diagnostic features.

The detailed description of the assumptions of the diagnostic mission is shown in [9]. The paper is divided into 6 parts. In Part 1 the authors introduce current knowledge on belt conveyors' monitoring systems, the objectives of THING project and challenges in evaluating the condition of the conveyor gearbox. The construction and characteristics of belt conveyors are presented in Part 2, while the construction and anticipated functions of inspection robot designed by THING team are described in Part 3. Part 4 covers the goals of the diagnostic mission and the procedure of measuring the diagnostic parameters on the belt conveyor gearbox. Part 5 describes the method of identifying diagnostic features from diagnostic signal. Part 6 is the conclusion.

2 Construction and characteristics of belt conveyor

A single belt conveyor is the part of the whole horizontal continuous transport system. It operates continuously (on 24-hour basis irrespective of short service breaks). The conveyor transports material on its looped belt. The belt constitutes the closed loop, thus, there are two sides, upper - carrying side (top link) and bottom - return side, separated by front and backing drums. The belt loop is located on respective roller bearings - idlers and drums between the front station and turning station of the conveyor. The points are located respectively at the front and back of the conveyor. The section between one point and the other is called a conveyor route. The conveyor route consists of the load bearing structure. This structure supports conveyor's components and balances pressures resulting from belt tensions and the weight of material and the belt itself. Alike the front point, the backing point is the separate construction. It supports components which construct the back part of the conveyor. At that point the material is placed on the belt. A drive unit propelling the belt is assembled at the front point. Depending on its function and length, the drive consists of 1-4 engines usually featuring the same technical parameters. The single drive unit is built of an engine, coupling and gearbox (usually two-stage or three-stage). The combination of rigid coupling and fluid coupling is commonly used to dampen the sudden load shocks during exploitation. Fig. 3 depicts the construction of the drive unit.

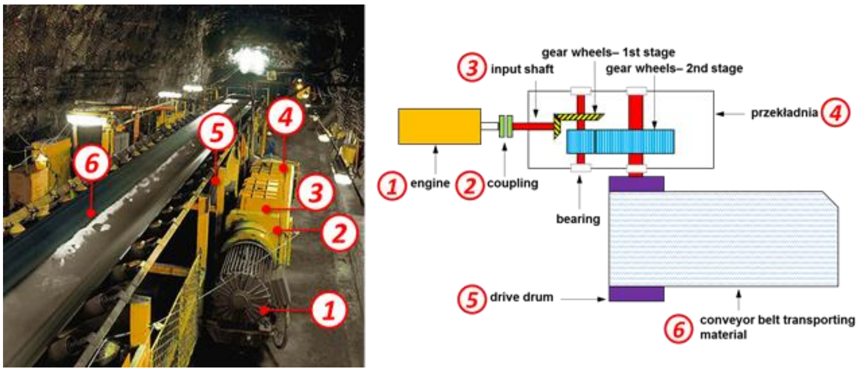

Fig. 3. The components of the conveyor drive unit (left) and the construction scheme of the conveyor drive unit (right).

3 Construction and anticipated functions of inspection robot

The robot is a four-legged (Fig. 4), module platform intended for inspection underground works (condition evaluation, emergency actions etc.) which are performed remotely and autonomously with the use of wireless connection. The robot is powered with a lithium-ion polymer battery. The whole sensory layer on the platform weighs no more than 5kg. There are the following sensors:

- inertial sensors (3-axis accelerometers, gyroscope, magnetometer)
- adaptive feet,
- LIDAR scanning,
- laser scanner,
- head with a tilted panel and a high-quality, infrared zoom camera,
- thermal camera,

- sensors for environmental parameters and toxic gases detection (CO, H^2S).

Fig. 4. ANYmal legged robot used in the project [**Błąd! Nie można odnaleźć źródła odwołania.**].

Because of the carbon fibre construction, the robot weighs approximately 30 kg. The main body and the drive units are water- and dustproof. There are 12 actuators on the robotic legs, which allow collecting touch interactions with the surrounding, based on the techniques of full robotic body control and performing dynamic movements, such as jumping and running. In the course of THING project, the focus has been directed towards kinematic robot design to obtain full mobility for both agile passing through obstacles and stairs and convenient transportation, mainly of compactly stored elements. “360^o rotation” in all joints facilitates the robot’s climbing all kinds of obstacles and getting up once fallen. The robot is controlled by designed algorithm which steers its activity, namely the configuration of its legs and the position of its steps in line with the real-time parameters collected by the sensory layer. Regarding hardware, there are three independent computers connected by the intranet. The first computer (movement) controls the motor unit. The second computer (navigation) controls the perception of surrounding (mapping), location, navigation and autonomic performance of the mission. The third computer (inspection) controls the conditions of quarry, drivers and conveyor route and identifies abnormal phenomena/events.

4 Diagnostic mission - diagnostic parameters measurement recorded on the belt conveyor gearbox

Consequently, the robot is designed to perform inspection of the whole conveyor, including the condition of mining excavation. The detailed description of inspection, challenges in retaining functionality of the conveyor and the expected results of the robot’s functioning are included in [9]. The main objective of this paper is only the diagnostic inspection of the conveyor drive unit gearbox, specifically the method of measurement and identification of diagnostic, damage-oriented features.

The mission of the robot is to perform the work of maintenance employee which constitutes evaluating technical condition of the pairs of kinematic gearboxes by vibration diagnostic technique. Currently this process is performed with the use of portable measurement unit with 3 vibration sensors and tachometer probe which measures rotational speed of the engine (Fig 5).

Fig. 5. Maintenance inspection for conveyor gearbox in underground mine - vibration measurement.

The implementation of the robot aims at completely eliminating the human role in evaluating the gearbox's condition. The measurement procedure depicted in Fig. 6a. and Fig. 6b indicates the measurement points. This measurement method does not require assembling sensors to the drive unit. The measurement is performed with haptic sensing.

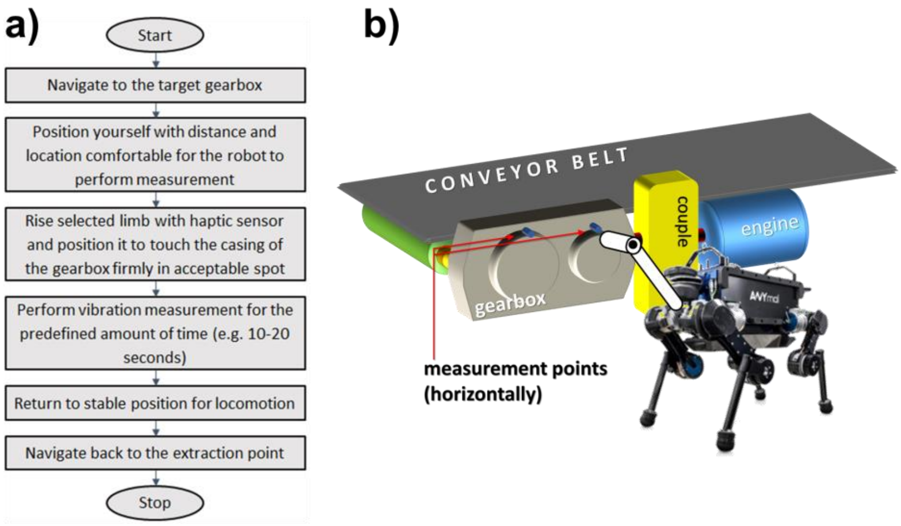

Fig. 6. a) Procedure of inspection mission with Anymal robot for belt conveyor gearbox, b) measurement points.

5 Method of identifying diagnostic features to examine shafts, gearings and bearings of the conveyor gearbox

Diagnostic features of multistage gearboxes can be identified by transforming signal into frequency domain, and further defining, in its spectrum, components relative to the specific vibration elements (shafts, gearing, bearings) (Fig. 7c). Thus, the comprehensive condition of the components of the gearbox under inspection might be obtained. Fig. 7. shows examples of vibration signals and their spectra from gearboxes in good and bad condition.

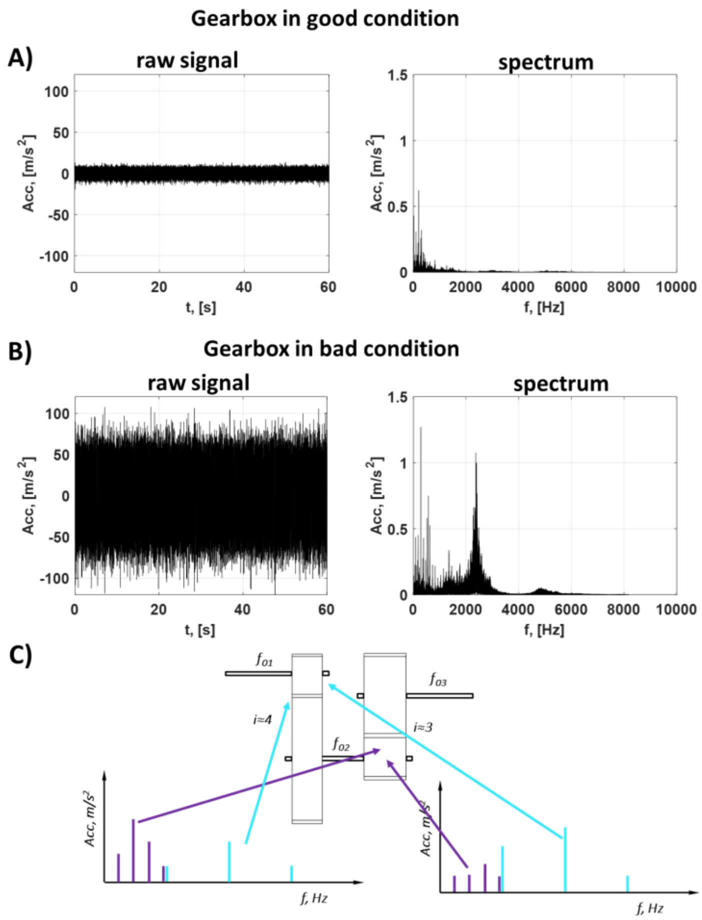

Fig. 7 Vibration signal and its spectrum from the conveyor gearbox in a) good condition and b) bad condition, c) Signal spectrum components as diagnostic features.

The solution suggested in the paper employs the broadband Fourier transform to translate the signal into frequency domain. The methodology adopted the vibration measurement for 20s. Next, the raw signal was evenly segmented into 20 sections. Repetitively, each consecutive 1-second section of vibration signal was converted into frequency domain and all obtained sections were totalled within three bands of spectrum frequency (for shafts: 10-100 Hz, for gears: 100-3500 Hz, for bearings: 3500-10000 Hz), Fig. 8.

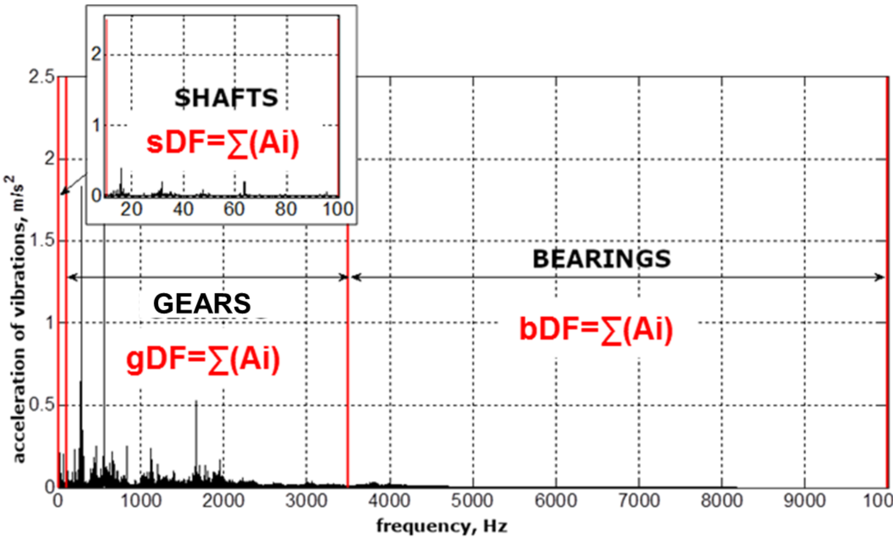

Fig. 8 Three key spectrum bands for determining diagnostic features for shaft, gearing and bearings.

The measurement results in 20-second time series (with sample period of 1s) of diagnostic features sDF (shafts diagnostic feature), gDF (gearbox diagnostic feature) and bDF (bearings diagnostic feature) which define the condition of, respectively, shafts, gears and bearings, Fig. 8.

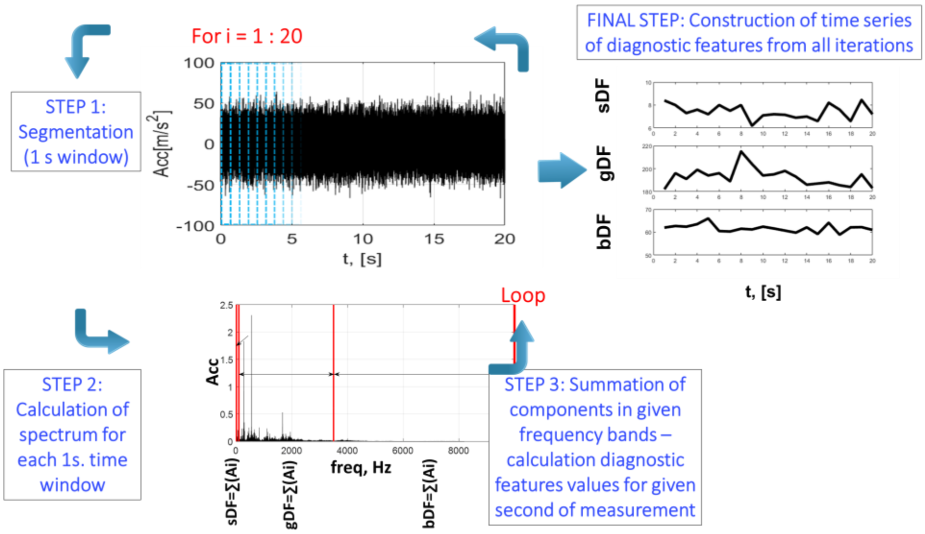

Fig. 8 The methodology of identifying diagnostic features from vibration signal spectrum.

6 Conclusion

The paper presents the general objectives of diagnostic mission of the legged inspection robot for monitoring mining belt conveyors. The challenge of managing the conveyor transport network has been discussed herein. It has been recommended to perform the diagnostics mission with the legged diagnostic robot. Thus, the complete procedure of vibration measurements on the gearbox housing of the conveyor has been performed. The main objective of the mission was to identify faulty diagnostic features within the vibration signal. The paper outlines the set of shafts, gearing and bearing features and algorithm to define the diagnostic features.

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References

1. Stefaniak, P., et al. "Some remarks on using condition monitoring for spatially distributed mechanical system belt conveyor network in underground mine-a case study." Condition monitoring of machinery in non-stationary operations. Springer, Berlin, Heidelberg, 2012. 497-507.

2. Stefaniak P., Wodecki J., Zimroz R. (2018) Maintenance Management of Mining Belt Conveyor System Based on Data Fusion and Advanced Analytics. In: Timofiejczuk A., Łazarz B., Chaari F., Burdzik R. (eds) Advances in Technical Diagnostics. ICDT 2016. Applied Condition Monitoring, vol 10. Springer, Cham.
3. Wei, Y., Wu, W., Liu, T., Sun, Y., 2013. Study of coal mine belt conveyor state on-line monitoring system based on DTS, Proceedings of SPIE - The International Society for Optical Engineering 8924, , Article number 89242I.
4. Kuttalakkani, M., Natarajan, R., Singh, A.K., Vijayakumar, J., Arunan, S., Sarojini, L., Sensor based effective monitoring of coal handling system (CHS), International Journal of Engineering and Technology 5/3, pp 2432-2435.
5. Eliasson, J., Kyusakov, R., Martinsson, P.-E., Eriksson, T., Oeien, C., 2013. An internet of things approach for intelligent monitoring of conveyor belt rollers, 10th International Conference on Condition Monitoring and Machinery Failure Prevention Technologies 2013, CM 2013 and MFPT 2013 2, pp. 1096-1104.
6. Sadhu, P.K., Chattopadhyaya, S., Chatterjee, T.K., Mittra, D.K. 2008. Online monitoring and actuation for curing of rubber conveyor belts, Journal of the Institution of Engineers (India): Mechanical Engineering Division 89, pp 31-35.
7. Keerthika, R., and M. Jagadeeswari. "Coal conveyor belt fault detection and control in thermal power plant using PLC and SCADA." Int. l J. of Advanced Research in Comp. Engineering & Technology (IJARCET) 4 (2015): 1649-52.
8. Sawicki, M., et al. "An automatic procedure for multidimensional temperature signal analysis of a SCADA system with application to belt conveyor components." Procedia Earth and Planetary Science 15 (2015): 781-790.
9. Zimroz, R., et al. "Why Should Inspection Robots be used in Deep Underground Mines?" Proceedings of the 27th International Symposium on Mine Planning and Equipment Selection-MPES 2018. Springer, Cham, 2019.
10. R. Käslin, H. Kolvenbach, L. Paez, K. Lika and M. Hutter, „Towards a Passive Adaptive Planar Foot with Ground Orientation and Contact Force Sensing for Legged Robots," 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Madrid, 2018, pp. 2707-2714.
11. Bednarek, J. Bednarek, M. Wellhausen, L. Hutter, M. Walas, K. "What Am I Touching? Learning to Classify Terrain Via Haptic Sensing", 2019 IEEE International Conference on Robotics and Automation (ICRA), Montreal, 2019