CORE DAMAGE INCREASE ASSESSMENT IN THE CONVEYOR BELT WITH STEEL CORDS

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Summary

As a result of a job commissioned by an external company, over the period of one year 3 measurements were performed on a steel-cord conveyor belt in one of Polish underground copper ore mines. The tests were performed with the DIAGBELT system for automatic belt diagnostics which was developed at Wroclaw University of Science and Technology.

The non-invasive tests revealed that new damage developed in the belt core and that the already existing damage became more extensive. The factor of mean defect number per 1 meter of belt or the number of defects on a given belt section are not sufficient to effectively describe belt technical condition. Quantitative information should be extended with the total surface area of the defects. The analysis of the test results showed that estimations based on 3 measurements are insufficient and that verification should be performed after more measurements are obtained. In addition, the estimations for the complete belt loop are only approximate, as the damaged sections were cut out in the periods between the measurements and replaced with new, undamaged sections.

Research has shown increase in the number of defects that amounted to 33.17% and total surface area of all defects increased by 57.35% over a period of 9 months.

Keywords: conveyor belts, non-destructive testing, diagnostics, DIAGBELT

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Streszczenie

W związku ze zleceniem wykonanym dla firmy zewnętrznej wykonano 3 pomiary, w okresie roku, na taśmie przenośnikowej z linkami stalowymi w jednej z polskich kopalni podziemnych rud miedzi. Badania rdzenia taśmy zostały przeprowadzone systemem do automatycznej diagnostyki DIAGBELT opracowanym na Politechnice Wrocławskiej.

Badania nieinwazyjne taśmy wykazały powstawanie nowych uszkodzeń rdzenia, jak również powiększanie już istniejących. Współczynniki średniej liczby uszkodzeń na metr czy liczba uszkodzeń na odcinku taśmy są niewystarczające do oceny jej stanu technicznego. Informacje ilościowe powinny zostać rozszerzone o całkowite pola powierzchni uszkodzeń. Analiza wyników wykazała, że prognozy na podstawie 3 pomiarów jest niewystarczająca, a weryfikację powinno przeprowadzić się po większej ilości pomiarów. Dodatkowo prognozy dla całej pętli są orientacyjne, ze względu na wycinanie uszkodzonych odcinków, a następnie zastępowanie ich nowymi, nieuszkodzonymi odcinkami w okresach pomiędzy pomiarami.

Badania pozwoliły wyznaczyć procentowy przyrost liczby uszkodzeń, który wyniósł 33.17%, a przyrost całkowitej powierzchni uszkodzeń wzrósł o 57.35% w okresie 9 miesięcy.

Keywords: taśmy przenośnikowe, metody nieinwazyjne diagnostyka, DIAGBELT

1. INTRODUCTION

Since they can be operated continuously, belt conveyors are commonly used in mining industry and play an important role in main bulk material haulage systems. Conveyor belt constitutes the most expensive and the most damage-prone part of a belt conveyor, since it has direct contact with mined material. The belt is subjected to a continuous process of wear and tear, but the rate of the process is not constant. As the belt's operating time increases, the density of core defects increases in a non-linear manner [1]. Predicting the level of the belt's ultimate limit wear, performing current repairs and disassembling the belt for regeneration at a proper moment are all key issues from the perspective of maximizing belt lie on the conveyor

and preventing emergency (unplanned) and costly downtime.

Previous research into the magnetic tests of the core of steel cord conveyor belts [2, 3], focused primarily on the design, development and potential of the DIAGBELT diagnostic system. The data presented in these works were related to individual tests, and this fact precluded the evaluation of the degree of belt wear on a tested conveyor.

First research into magnetic inspection of conveyor belt core was performed by Harrison in the 1970s [4]. The method consists in recording the changes of magnetic field in magnetized steel cords of the belt core. The changes of magnetic field are generated by damaged (broken, corroded) or missing cords and by splices of belt sections.

Although other research [4-11] into the application of magnetic method to the diagnostics of conveyor belt core focused on the development of own systems, little attention was paid to the rate of belt wear and ultimate limit belt wear was not identified.

Recent studies [12] have confirmed the possibility of detecting even the smallest damage of steel cords in conveyor belt. Currently used post-processing methods also allow to denoise low-amplitude signals [13]. By that means it is possible to recover information about the least damage when the information is in the signal at the noise level.

NDT-based methods have been also recently introduced in mining industry. They are successfully used in the diagnostics of the technical condition of belt conveyors. Earlier research in this area focused on others individual elements of the conveyor: drives [14], idlers [15], gearboxes [16].

2. METHODOLOGY

The tests of conveyor belt core were performed using the DIAGBELT system, which was described in detail in previous publications [2, 3]. The tests were commissioned by an external company. Three measurement procedures were performed, with the following time gaps between each other:
a) 6 months between the first and the second measurement,
b) 3 months between the second and the third measurement.

The generated magnetic signal is influenced by many factors. In order to analyze the degree of wear and the rate of damage increment, the measurement procedure was unified. This eliminated the influence of individual parameters (belt vibrations, distance between the magnetic probe and the belt, etc.) on the results from different periods, allowing the comparison of the results. Fig. 1 shows the method for mounting the measurement system to the conveyor's frame.
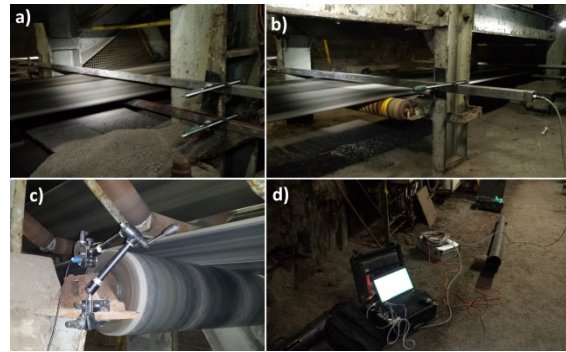

Fig. 1. DIAGBELT system mounted on the investigated conveyor; a) permanent magnet bars, b) magnetic head, c) tachometer, d) data acquisition module and a portable computer with the software

3. THE TESTED OBJECT

The tested steel-cord conveyor belt is operated in an underground copper ore mine. Successive measurements revealed differences in the length of the belt loop and in the number and type of splices. The differences resulted from the works carried out by the miners, i.e. from inserting new sections, removing damaged fragments, changing splice type or replacing the splice with a new one. All data related to the tested conveyor belt are shown in Table 1. Such parameters as belt length, time of complete belt loop cycle, or the number and type of splices are related only to the third (last) measurement.

Table 1. Data related to the tested conveyor belt

Belt type	ST
Belt strength [kN/m]	3150
Belt width [mm]	1200
Number of splices [total / vulcanized / mechanical]	40 / 31 / 9
Mean belt velocity [m/s]	2.5
Belt loop length, taken from the system [m]	4407
Belt loop measurement time [s]	1789

4. RESULTS & ANALYSIS

After all measurements had been performed, the number of defects proved to be insufficient indicator of the rate of conveyor belt wear. The tests of some sections revealed that new damage developed in the belt core and that the already existing damage became more extensive. This may locally lead to a decrease in the number of defects, although their total surface area will increase. An example of of such scenario is presented in Fig. 2.
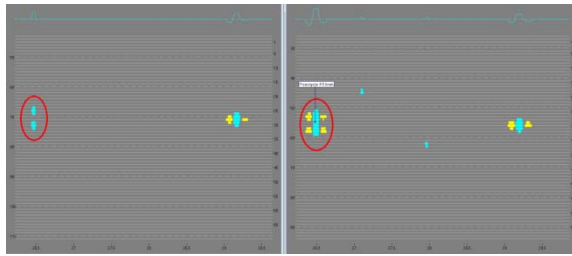
Fig. 2. An example of the development of two
small areas of damage (left side) into a single large
one (right) in CordBreak Analysis - time between
measurements: 9 months

From the perspective of the type of defects, the majority of them consisted of the ones that caused the discontinuity of one or more cords. The highest concentration of defects was observed in middle of the trough and the edges of the belt. Fig. 3 shows core damage on one of the sections (from splice to splice) of the belt tested with the CordBreak Analysis application.
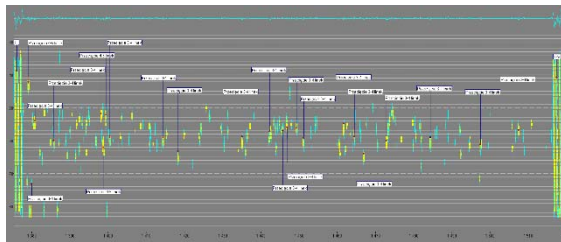

Fig. 3. Belt core damage on one of the sections
having length equal to 120 m

Table 2 shows the number of defects, the total surface area of the defects and the increment of damage both between the tests and in relation to the first test. Over that time, no significant or abnormal increase in the number of defects or in the size of the surface areas of core defects was observed.

Table 2. Increase in the number and in the total surface
area of defects between the tests
(*- 9-month increment, **- 6-month increment)

Measurement	Number of defects	Increase in the number of defects [%]	Total surface area of all defects [m²]	Increase in the total surface area of defects [%]
1	3624	21.80*	36.6	34.04
2	4414		49.06	
3	4826	9.33**	57.59	17.39**
		33.17*		57.35*

The comparatively slower increment rates than the ones recorded in the previous period are the result of the increasing share of new or almost new belt sections in the loop (insertions) while the damaged sections were removed. In the first period, 100 m (7 sections) of unworn belt were observed, while in the second period there were already

approx. 155 m (9 sections) of such belt. This fact influences the general result, since the insertion of new belt is typically performed to replace the belt sections which show the most extensive wear. Also, as part of splicing procedure, significant defects are removed and replaced with new fragments. The belt loop between the second and the third measurement was shortened by 9 meters of worn belt. As a result, the rate of increment decreases for both the total defect number and the defect surface area. The rate (increment per unit of time) was lower, as the defects in the removed segments were no longer included in the next measurement. Therefore, damage density (the number of defects per one running meter of belt) and mean defect area per belt section seem to constitute more efficient measures of belt wear, since they are independent of the length of segments. The total number of defects and their area should not be the basis for predicting the wear rate of conveyor belts. In the analyzed case, the number and length of short segments (9 x below 20 m) is low (155 m per 4.4 km of belt), and hence their influence on the predictions is limited. Importantly, the increase in the number of defects is non-linear, but directly proportional to the square of time flow (Fig. 4)
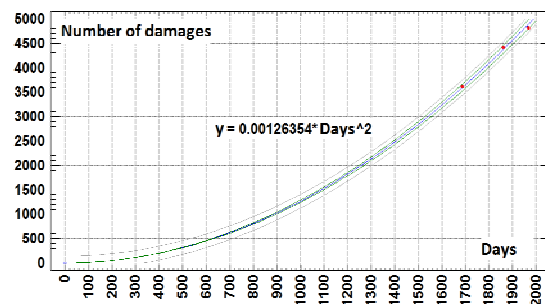

Fig. 4. Changes in the total number of defects for
the belt loop with 3 measurements and with
confidence interval at 95%

It is highly worrying that the change in the total area of defects may produce inconsistent predictions. Since the predictions are based only on 3 measurements and on the function passing through the beginning of the coordinate system (no damage observed in the belt newly installed on the conveyor), a significant portion of uncertainty is introduced about the future change rate. Fig. 6 shows two selected functions (a quadratic function and a 3rd degree polynomial function) which ensure high consistency with empirical data (R^2= 99.67% and R^2=100%), and yet offer significantly different predictions about future changes. It seems that due to the lack of historical data about the level of damage in the first years of belt operation, a prediction method should be chosen which is better adjusted to the measurements performed in a local environment of 3 measurements. This is possible if a third polynomial is used, since the plot of this function practically crosses all the three points.

Unfortunately, the rate of damage surface increment is then higher than for a quadratic function. The prediction should be verified on the basis of future measurements, since the differences between predictions increase as time period becomes longer. The differences may be even greater than suggested in Fig. 5, since the increment rate is non-linear and each new measurement shows the rate of surface increment to be relatively higher than expected.

The predictions of total changes in the complete loop are only approximate, since their accuracy is affected by the replacement of old belt sections with new fragments (insertions). The growing number of sections having limited length (under 20 m) and substitution of vulcanized splices with mechanical splices reduce the belt's reliability. Each new splice constitutes another weak link in a serial structure, which a belt loop becomes from the perspective of reliability. Due to this serial structure, predictions should be prepared for each individual section, since the continuous operation of a belt conveyor depends on the condition of its weakest link, i.e. on a belt section showing the most extensive wear or on a disconnecting splice. Belt defects occur randomly, but their development is the result of degradation processes (impacts of mined material, friction, fatigue, corrosion, etc.) whose results until now could not be reliably quantified. Currently such quantification is possible with a high resolution magnetic system which allows the assessment of both the number and the scale of defects, as well as their development over time. However, the reliability of future predictions depends on the number of measurements, and this number so far is limited.
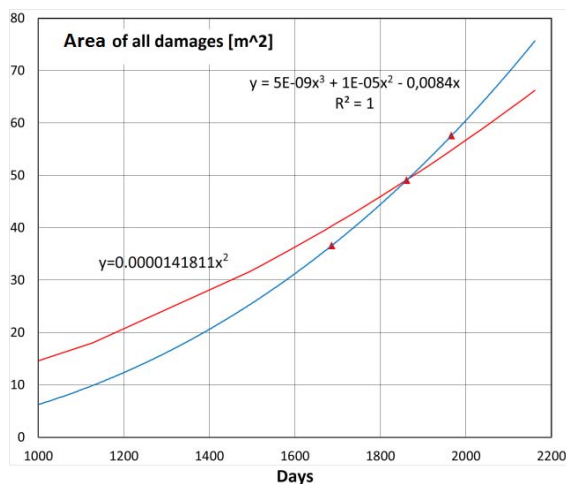

Fig. 5. Changes in the total defect area for the belt loop with 2 predictions based on 3 measurements

A mention was made above about the need to average the results since fragments of the damaged belt were removed and replaced with new fragments. Fig. 6 shows the number of defects on each belt section and the mean number of defects per one running meter of the belt, and Fig. 7 shows the

surface areas of defects on each belt section together with mean surface area of defects for the complete belt. The results include the data from all 3 measurements.
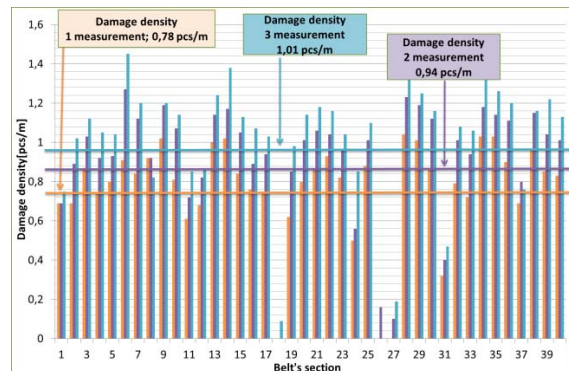

Fig. 6. Number of defects on each belt section and the mean number of defects per one running meter of the belt
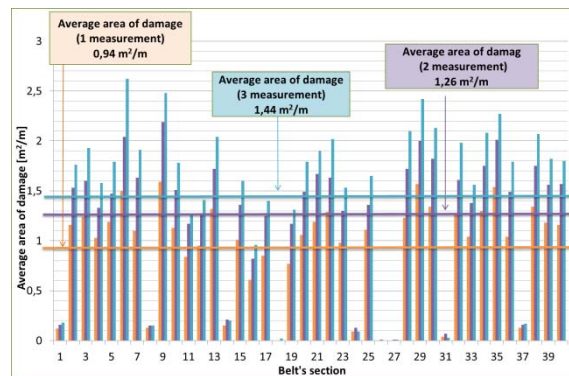

Fig. 7. Surface areas of defects on each belt section together with mean surface area of defects for the complete belt

Based on the above results and on the mean surface area of core defects, a curve of belt wear was prepared (Fig. 8). This indicator offers substantially more information on the degree of the damage to the steel-cords, than the number of defects does. This parameter also allows greater independence of the service works, such as the replacement of belt sections in the periods between measurements.

5. CONCLUSION

If assumed that on its installation the belt showed no trace of damage, the increment in the surface area of defects in the period of 2.5 years from the last measurement was three times higher than over the first three years of belt operation. According to the prediction, over the period of six months from the last measurement, the surface area of defects will increase fourfold and reach the value of 2 m^2. However, as has been already mentioned, a more reliable prediction of the remaining life for individual sections will require a greater number of measurement points. They will enable a more

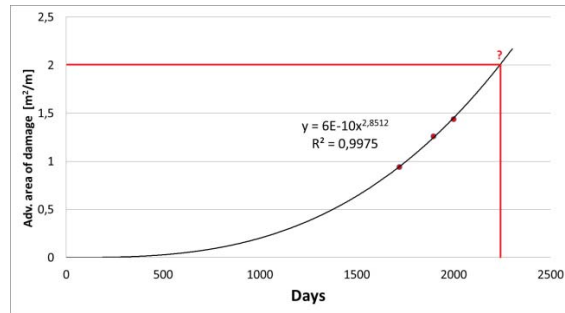accurate curve and the validation of the results obtained so far.

Fig. 8. Increase in the mean surface area of defects for belt segments, with prediction from 3 measurements

The consideration of the earlier-mentioned factors – damage increment per 1 running meter, the surface area of defects and the rate of damage increment – allows a conclusion that the tested belt does not show a dangerous level of wear and tear and may be further operated in the same conditions.

However, in order to ensure further safe operation of the belt, the most extensive defects should be immediately repaired and the locations showing substantial concentration of defects and significant weakening in the cross-section should be inspected.

The next test of the belt core is recommended within 6 months from the previous measurement, in order to control the rate of damage increase and to more precisely estimate the remaining life of the belt loop or its individual sections.

The DIAGBELT system for magnetic tests of conveyor belt core also provided information about some core defects which had a significant influence on the strength of the belt (more than ten cords). This information was passed to the mine. Particular attention should be also paid to locations with increased density of the already existing, smaller defects, since they may develop and combine into larger defects.

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