EVALUATION OF THE QUALITY OF STEEL CORD BELT SPLICES BASED ON BELT CONDITION EXAMINATION USING MAGNETIC TECHNIQUES

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Summary

The results of long-lasting research into steel cord belt splices strength performed at Wroclaw University of Technology Belt Conveying Laboratory indicate that the quality of splicing procedure greatly affects splice strength. Properly performed splices have strength of up to 100% of the nominal strength of belt, while the strength of improperly performed splices may be 70% or even lower.

Each mistake made during splicing procedure results in decreased splice strength. Varying operating conditions and unstable conveyor operation may lead to exceeding actual strength values of performed splice. This may in turn lead to the splice breaking and bring the conveyor to emergency stop, until the damage is repaired. Such emergency stop results in a financial loss due to high cost not only of resplicing and belt loop restretching, but also of removing spilled material and of complete transportation system downtime. Practical mistakes made during splicing result in inappropriate splice geometry, which decreases splice strength and in extreme cases may lead to premature splice damage.

Key words: conveyor belts, splices, non-destructive testing, diagnostics, defective splicing, automatic detection, magnetic method

OCENA JAKOŚCI POŁĄCZEŃ TAŚM Z LINKAMI STALOWYMI
NA PODSTAWIE ICH DIAGNOSTYKI MAGNETYCZNEJ

Streszczenie

Wyniki badań wytrzymałości połączeń taśm z linkami stalowymi prowadzone od wielu lat w Laboratorium Transportu Taśmowego Politechniki Wrocławskiej wykazały, że jakość wykonania połączenia ma istotny wpływ na jego wytrzymałość. Poprawnie wykonane połaczenia osiągają wytrzymałość rzędu 100% wytrzymałości nominalnej taśmy, natomiast wadliwie wykonane stanowią 70% a nawet mniej.

Każdy błąd popełniony podczas wykonywania połączenia powoduje obniżenie jego wytrzymałości. Pod wpływem zmiennych warunków eksploatacyjnych i nieustalonej pracy przenośnika może dojść do przekroczenia rzeczywistej wytrzymałości wykonanego złącza. Może spowodować to jego zerwanie oraz przerwę w pracy przenośnika, aż do momentu usunięcia awarii. Awaryjny przestój z tego powodu związany jest nie tylko z wysokimi kosztami ponownego wykonania połączenia i napięcia pętli taśmy, lecz również powoduje szereg strat związanych min z kosztem usunięcia rozsypanego urobku, oraz przestojem całego układu transportowego. Błędy popełniane w praktyce przy wykonywaniu połączeń skutkują niewłaściwą geometrią złącza , która obniża wytrzymałość połączenia, a w skrajnych przypadkach może doprowadzić do jego przedwczesnego zniszczenia.

Słowa kluczowe: taśmy przenośnikowe, złącza, metody nieinwazyjne, diagnostyka, wady wykonawcze złącza, automatyczna detekcja, metoda magnetyczna

1. INTRODUCTION

Outsourcing of conveyor belt repairs and splicing procedures caused mines to lose control over the quality of splices. Although supervision of splicing operations is possible, the mine would have to assign its worker for the duration of the procedure. Considering the number of splices performed in mines, this would contribute to increased production costs. Security measures in the form of warranty and other possible compensation for emergency downtime allow to cover the loss to some extent. At the same time, however, the mine may be exposed to long-lasting lawsuits over damages, as the results of defective splicing become apparent only after long operating time.

2. SPLICE REQUIREMENTS

PN-C-94147 norm includes requirements regarding hot-vulcanized splice geometry. Splice dimensions vary and mainly depend on the strength of connected belts. The number of steps depends on belt strength and design (distances between cords, cord diameter) [4]. The required dimensions are presented in Table 1.

Steel cords in such a splice are not mechanically connected with each other. Splice strength depends solely on adhesion force between cords and core rubber.

Splices may take the form of step or bevel splices. For bevel splice, slope length should be 0.3B or 0.4B, where B is belt width.

Table 1. Splice dimensions in steel-cord belts [4].

Belt type	Number of steps	Step length l_{st} [mm]	Splice length L_p [mm]
St 1000	1	300	600
St 1250	2	300	900
St 1600	1	400	700
St 2000	2	450	1 200
St 2500	2	600	1 500
St 3150	2	750	1 800
St 4000	3	800	2 700
St 5400	4	1 000	4 500

3. SPLICE COST

Splicing is an expensive stage mainly due to time consumed by connection procedures and curing process. As conveyor operation is interrupted, downtime cost is generated. Although minimization of curing time limits splicing cost, the price is usually lower quality and higher risk of damage.

Splicing cost should also include material and labor cost as well as the cost created by shortening the belt as a result of splicing.

$$K=K_m+T_zK_o+L_zK_t, \text{ [pln]}$$

where:
K – splicing cost, pln,
K_m – material cost, pln,
T_z – total splicing time, hours,
K_p – unit cost of labor, pln/hour,
L_z – splice length, m,
K_t – unit cost of belt, pln/m.

Splicing time and splice quality also have influence on additional costs. Low splice quality negatively affects its service life and this is reflected in the number of splicing operations performed in a year. During splicing operations and curing processes the belt conveyor is stopped, which may, although not necessarily, generate downtime cost. If splice replacement is performed as a preventive action during scheduled stoppage, downtime cost does not occur. Unfortunately, when splice replacement takes place as a result of damage that occurred during operation, not only additional costs of damage repair are involved (removal of the material, belt stretching etc.), but also unscheduled downtime is extended. This may entail creation of production losses, which may be impossible to be reduced after the conveyor's normal operation is restored. Production losses in particular situations may be very high and reach up to 1000 USD/hour [2]. Low quality of mechanical fasteners and high cost of emergency downtime forced the management of Consol Energy hard coal mines to commission designing diagnostic devices that would allow for preventive replacement of splices which showed signs of disconnection.

Monitoring of current splice image changes in comparison to a reference sample and to splice condition observed after splicing procedure has been performed should also prevent damage, while splice quality control should further translate into increased durability.

Article [3] shows the correlation between splice quality and splice durability. The majority of analyzed samples had at least one defect, which reveals the scale of faulty splice problem. Elimination of mistakes should be the means to reducing failure frequency and thus increasing the effectiveness of belt conveyor transportation.

Steel-cord belt diagnosticsusing non-destructive methods allow for detecting and monitoring events along the belt's total length. Such diagnostics also enable assessing splice quality. Tests based on this method have been performed with Diagbelt diagnostic system developed at Machinery Systems Division at Wroclaw University of Technology, Faculty of Geoengineering, Mining and Geology [1]. The system offers to its user a new tool enabling splice quality control during technical acceptance of outsourced jobs, as well as during the belt's further operation.

4. DIAGBELT SYSTEM MEASUREMENTS

The system's head is 3 m long and has 7 modules, each comprising 16 coils (Fig. 1). This gives a total of 112 measuring channels, which allow to take measurements with 25 mm resolution. The coils allow to take bipolar measurements. Measurement signals from induction coils are amplified and sent to a recorder. Coil sensitivity and measurement frequency are set by the operator. The recorder collects data from the measuring bar and a connected computer allows the data to be saved and exported to a CSV (Comma Separated Values) file. Data from the CSV file are then fed into a computer program designed in LabView environment.

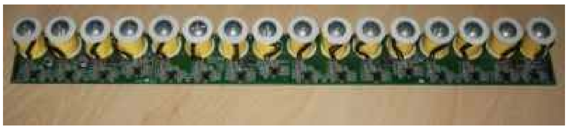

Fig 1. Module with magnetic coils

A non-destructive testing (NDT) is performed on flat belt during conveyor's operation . Two permanent magnets (Fig. 2) and the measuring bar (Fig. 3) are placed in purpose-made holders. The design of the holders allows for easy assembly and disassembly on/off the conveyor and for regulating the distance from the inspected belt [5, 7].

At an event location, induced magnetic field of magnetized cords in belt core decreases. At each field variation current flows in the coil (coils) of the measuring head – in accordance with electromagnetic induction law.

A significant change of induced magnetic field occurs in splice area, due to increased number of cords in the connected belts. The change may be observed across the total width and along the total length of the splice, which allows to obtain full diagnostic image.

Fig. 2. Two permanent magnet bars mounted in the holder

Fig. 3. Measuring head mounted in the holder to the conveyor's frame

An implemented encoder (Fig. 4) provides information on conveyor velocity and enables recording results, thus allowing to find splice or event place.

Fig 4. Measurement of conveyor velocity with magnetic encoder

Acquisition of measurement data is performed using BeltGuard recorder commercially offered by Beltscan (Fig. 5). The recorder requires external power supply e.g. from a diesel generator. After measurements have been taken it is possible to sent the collected data to a laptop computer, which allows to further process and analyze the data.

Fig. 5. Belt Guard recorder from Australian company Beltscan

5. DIAGBELT SYSTEM MEASUREMENT RESULTS

Diagbelt uses BeltGuard system's measuring head and data acquisition module. After measurements have been taken on the conveyor, raw data may be displayed directly in 2D mode using Belt Analysis software (Fig. 6).

Owing to the head's high resolution, the image allows for quick estimation of splice quality (splice geometry), as well as for event location. Figure 7 shows an event in mid-left part of the splice. The event may have occurred during belt operation or, in case no cover damage is observed, may be the result of defectively performed splicing procedure.

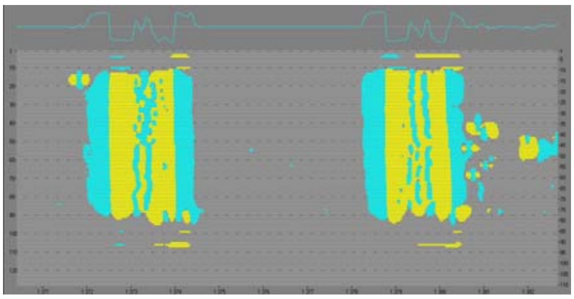

Fig. 6. 2D view of a splice in Belt Analysis software

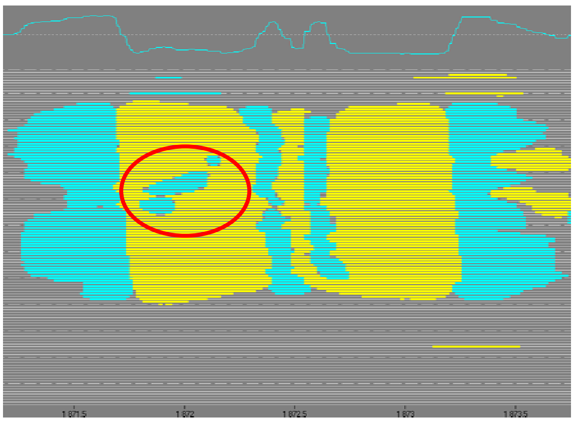

Fig. 7. An event in the mid-left part of the splice (marked with red color)

Diagbelt system allows for automatic detection of events and splices along with their geometry, as well as for visualization of inspection results (Fig. 8). Each section of belt loop is ascribed individual color in a five-grade scale, which shows its wear level (number of events per one meter of the belt).

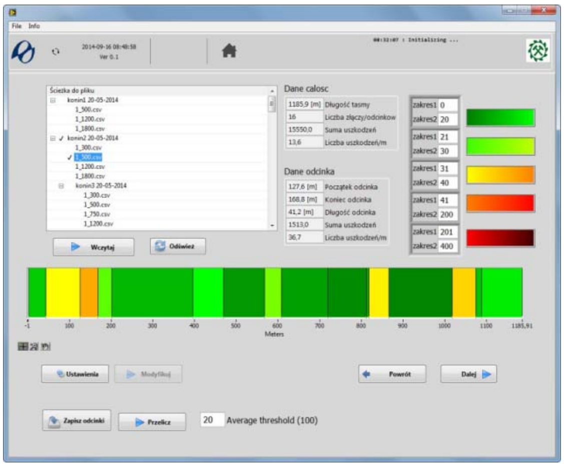

Fig. 8. Visualization of test results using Diagbelt system

Figure 9 shows an image of a proper splice, as its geometry would suggest. Figure 10 shows a damaged or defectively performed splice. At this stage of Diagbelt system development, the cause of the abnormality is impossible to be clearly established.

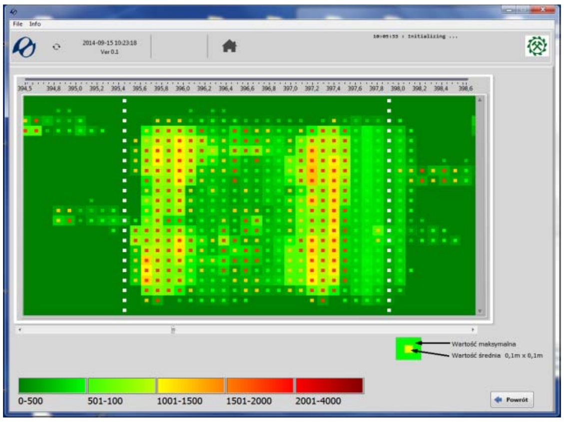

Fig. 9. Image of properly performed splice in the window of Diagbelt software

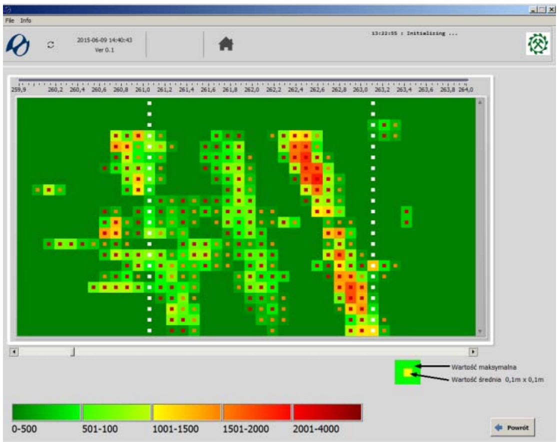

Fig. 10. Image of a damaged or defectively performed splice

6. CONCLUSION

In large Polish brown coal mines which make intensive use of belt conveyors for transporting both overlay and coal, separate service teams were assigned to repairing, splicing and regenerating belts. Meanwhile, conveyor service outsourcing was introduced worldwide [6, 7, 8]. The consequence is that mines are dependent on the quality of splicing procedures offered by external companies. Technical acceptance of outsourced jobs may be performed based on visual inspection of the splice’s external features, yet those are not of primary importance. One of particularly important features is compliance of splice structure with a reference sample selected optimally for particular conveyor, belt type and tensions existing. Unfortunately, these features are impossible to be inspected visually. Splice inspection could be performed using X-ray method , which offers clear image of cord alignment in the splice. However, large splice dimensions (belt width often exceeds 2 meters and may even reach up to 4 meters) on the one hand and small scanning and imaging window on the other hand make the procedure inconvenient as well as threatening to human health. Although an Australian company offers full scale splice inspection using X-ray methods [9, 10], such imaging is troublesome due to the large scale of the generator and special films, and thus also expensive. Progress in the field of belt monitoring should lead to using high-resolution magnetic scanners capable of two-dimensional visualization. Such devices offer images of splice structure that may be used in splicing quality inspection by comparing splice condition with a reference sample of a properly assembled splice. The reference sample could also be used to compare scans of splices assembled by external company, aiding technical acceptance procedures. Up-to-date splice conditions could also be compared, which would allow to estimate splice degradation level resulting from wear and fatigue processes. This is because splice is subject to damage caused by falling material like all other parts of the belt. Fatigue processes (bending on pulleys and idlers and cyclical tension changes) may additionally cause cords to lose grip with the gum, resulting in gradual or sudden splice break – an event that could be detected in case of regular monitoring (cyclical or continuous).

In order to accomplish this aim, research should be started that would lead to automating the process of identifying differences between actual image and standard sample and also to estimating the influence of those differences on decreased strength. Such research would also allow to use identified degradation rate to estimate belt’s remaining service life. Belt diagnostics laboratory at MSD has a magnetic belt scanner with own software and already started research into this problem.

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