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Maintenance of belt conveyors using an expert system based on fuzzy logic

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ABSTRACT

In recent years, conveyor belt transport systems have taken on a new significance due to numerous research studies on innovative design solutions. The application of these new developed solutions leads to considerable reduction in operational costs of transport systems, while ensuring their high reliability and service life at the same time. Nonetheless, there are still areas that pose challenge to both research and development. Typical challenges are analyzed in this paper. The solution to the problems of conveyor transport maintenance can be the implementation of a system for estimation of technical condition of conveyor belt joints. It serves as a second level safety diagnostic system for transport. Besides real-time measurements, the system enables a long-term analysis of historic data for every single joint that makes up the conveyor belt loop, from the moment of its manufacture to the final operation. The effectiveness of a conveyor belt diagnostic system primarily depends on the use of a decision supporting system. With adequate inference rules applied, this system would increase the effectiveness and shorten the time of decision-making as well as verify generated signals. The above tasks can be performed by a suitable expert system that predicts values of the analyzed time series, using the predicted values and inference rules to verify any potential false alarm signals at the same time. The idea and algorithm of such an expert system were presented in this article as well.

1. Introduction

New technological possibilities result in an extremely dynamic industrial development. Due to ever-increasing competition on the market, higher customer demands and pursuit of innovative products, manufacturers are compelled to implement more and more advanced engineering solutions, particularly ones that lead to higher efficiency and reduced operational costs. In effect, machinery and technological devices are becoming more and more complex, which imposes higher demands on their users, including the necessity of applying suitable methods and techniques to ensure durability and reliability of frequently complex and elaborate production systems [1,2].

In recent years, conveyor belt transport systems have taken on a new significance due to numerous research studies on innovative design solutions for conveyor belts [3–10]. The

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application of these new developed solutions leads, among others, to considerable reduction in operational costs of transport systems, while ensuring their high reliability and service life at the same time. Nonetheless, there are still areas that pose challenge to both research and development. As demonstrated in the studies [3,4,11], it is absolutely vital from a practical point of view that the service life of conveyor belt joints be made longer owing to the fact that these joints are crucial elements of the entire conveyor transport system. For instance, vulcanized and adhesive-bonded joints of textile-rubber belts are made up of lap joints, their theoretical durability for three separators amounting to only 67% of the belt's rated durability [4]. Moreover, the forces that affect the belt load and durability of both the belt and its joints vary during operation. For this reason, methods applied to this end, e.g. ones for determining non-stationary states, are often inaccurate, which results from lack of precise data and insufficient determination of boundary conditions. On the other hand, it is vital to optimize the belt tension force for various conveyor load conditions, as this should result in higher durability of both the belt and its joints. The application of a solution based on standard control algorithms seems, however, inadequate due to the nature of the problem as well as lack of both sufficient insight into the problem and measurement data.

2. Operation of an intelligent advisory system in considerable uncertainty conditions

The solution to the above problems of conveyor transport maintenance can be the implementation of a system for estimation of technical condition of conveyor belt joints [11] that serves as a second level safety diagnostic system for transport. Besides real-time measurements, the system enables a long-term analysis of historic data for every single joint that makes up the conveyor belt loop, from the moment of its manufacture to the final operation. The monitoring device can also be converted into an autonomously functioning instrument that can independently react to variable operational conditions and thus eliminate states that pose threat to the system's reliability, e.g. it can counteract belt failure by predicting the occurrence of operational parameters and their consequences. However, the vast number of data and information generated by the measuring system (which is the case when the monitoring covers a great deal of joints that are usually located on up to even several conveyors in a complex transport system) leads to a series of complications regarding interpretation of the collected data, which consequently hinders effective decision-making by the monitoring staff. In addition, given the specific nature of operation of conveyor belts (e.g. their exposure to high momentary loads), the measured discrete values of variations in length of an adhesive-bonded joint can generate false alarms that can result in unjustified stoppage of the transport system, unnecessary inspection of the joint or complicated and time-consuming examination of the generated signal by the operator. The system operator is then continuously required to take decisions, analyze a vast data set and observe changes therein, as well as predict the consequences of further changes in functional properties. This means taking decisions in uncertainty conditions [12,13], when we have no information about the probable occurrence of particular states (safe/emergency/alarm) and can only predict values of the analyzed signals that have the form of a discrete time series.

The conveyor transport system is an object that is affected by a number of factors. These factors are either imprecisely determined or difficult, if not impossible, to measure because of their random and incidental nature. This object is hard to describe owing to its dependence on numerous unpredicted variables that are often additionally difficult to be precisely determined. Failure-signaling symptoms can occur either once or many times; they can also have different intensity and nature. Another common problem here is lack of unambiguous information about the analyzed object and the required short time of a potential reaction. When equipping a comprehensive conveyor transport system with efficient and advanced monitoring and diagnostic systems, it is therefore necessary that sophisticated and intelligent tools be used to support the above. More specifically, the intelligent advisory system will be a dynamic system for the supervision of complex processes that are characterized by variable operating conditions and two time scales: micro- and macro-time scales [14], which is essential with regard to the entire life cycle of a single adhesive joint or a belt section that usually undergoes frequent relocations.

3. Inference supporting system based on fuzzy residuum evaluation in the diagnostics of conveyor belts

The effectiveness of a conveyor belt diagnostic system primarily depends on the use of a decision supporting system. With adequate inference rules applied, this system would increase the effectiveness and shorten the time of decision-making as well as verify generated signals. The above tasks can be performed by a suitable expert system that predicts values of the analyzed time series, using the predicted values and inference rules to verify any potential false alarm signals at the same time. The prediction of variations in length of an adhesive-bonded joint involves classification and estimation of time series. Although all standard classification and estimation methods can, under certain conditions, be also employed for prediction, the most effective method for predicting time series involves the use of artificial neural networks [15–20]. A supervision system for adhesive-bonded joints of conveyor belts should therefore also include an intelligent expert system based on the popular knowledge representation and rule-based systems (Fig. 1).

When measuring variations in length of belt joints by a computer-aided measurement system, it can be assumed that the observations are made at discrete and equal intervals of time t. For every joint we have data from the evaluation of its length ΔL in time moments $t-1$, $t-2$, …, $t-n$, which corresponds to the values of $\Delta L_{t-1}, \Delta L_{t-2}, \Delta L_{t-3}, \ldots, \Delta L_{t-n}$. The aim of the analysis is to determine values of elongation of the monitored conveyor belt joint $\overline{\Delta L_t}(w)$, denoting the prediction in a moment $t+w$, i.e. in advance w, with the lowest possible mean deviations $\Delta L_{t+w} - \overline{\Delta L_t}(w)$. When evaluating the potential