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Editorial

Energy Efficiency of Conveyor Belts in Raw Materials Industry

Mirosław Bajda [1,*,†], Monika Hardygóra [1,†] and Daniela Marasová [2,†]

1 Faculty of Geoengineering, Mining and Geology, Wroclaw University of Science and Technology, 50-421 Wrocław, Poland; monika.hardygora@pwr.edu.pl
2 Faculty of Mining, Ecology, Process Control and Geotechnology, Technical University of Kosice, 042 00 Kosice, Slovakia; daniela.marasova@tuke.sk
* Correspondence: miroslaw.bajda@pwr.edu.pl; Tel.: +48-71-320-68-92
† These authors contributed equally to this work.

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1. Introduction—Special Issue Information

Belt conveyors are presently the most common transportation machines used in surface and underground mining. Apart from the mining industry, belt conveyors are also used in cement and chemical industries, as well as in power plants and ports. Conveyor belt transportation technology used in global mining industry has undergone constant development. The advances are most clearly visible in long-distance belt conveyor designs. The two most important areas for belt conveyor development include first and foremost improving belt conveyor efficiency and extending the length of a single conveyor, which entails increasing the power of the drive mechanisms. High-power conveyors need considerable amounts of electric energy, and consequently, due to global increase in energy prices, they generate increased transportation costs. In recent years, very intensive research has been performed on lowering energy consumption of belt conveyor drive mechanisms. Extensive theoretical and experimental research demonstrated the potential for energy savings in individual components of belt conveyors, such as belts, idlers, gearboxes, couplings, drive systems, belt tensioning systems, etc. Identification of main resistance in belt conveyors is an example of one such research approach. The research proved that the feasibility of limiting electric energy consumption is linked to belt properties. Estimations suggest that implementing improved energy-saving belt with adequate parameters of rubber cover will allow for a significant decrease in conveyor primary resistance, which will result in decreased electric energy consumption by conveyor drive mechanisms.

Analysis of belt transportation systems only in Polish brown coal mines shows the scale of the problem. The "Belchatow" lignite mine, which extracts above 4×10^7 Mg of coal and more than 1×10^8 m^3 of overlay per year, may be a good example here. The transportation of materials in the "Belchatow" mine is performed with the use of belt conveyors having a total length of more than 160 km and accounts for approximately 50% of its electric energy consumption. This fact demonstrates both the economic and ecological importance of technologically optimizing belt conveyors in order to lower the energy consumption of drive mechanisms.

The proposal of topics for the Special Issue of the journal *Energies* includes the following research areas:

1. Energy-saving solutions in belt conveyor transportation—modeling of the operating conditions and dimensioning of conveyors, monitoring the condition of conveyor components, and predictive diagnostics.
2. New energy-saving solutions with respect to conveyor components, especially their drive systems, gearboxes, couplings, idlers, as well as devices for controlling and monitoring their operation.
3. Calculations of belt conveyor parameters and of energy savings due to conveyor speed adjustments, more efficient use of the transportation capacity, and optimal selection of conveyors for particular tasks.

4. Applications of environmentally friendly and economically justified design solutions aimed at improving the energy efficiency of belt conveyors and limiting their noise impact.
5. Optimizing the operation-related processes in belt conveyors (evaluation of the energy consumption, the durability, and the reliability of conveyor transportation systems).
6. Methods for the evaluation and measuring of both the quality of conveyors and their behavior during the starting process.
7. Experiments regarding the laboratory and in-service tests of belt conveyors and their components, such as belts, idlers, drives and gearboxes—new measurement and result-processing technologies.
8. The use of belt conveyors related to the monitoring of their condition, damage analysis, computer-aided management, as well as the identification of the properties of both, belts and their splices.

In the next section, we provide a brief overview of the papers published in the Special Issue according to the previously outlined thematic areas.

2. A Short Review of the Contributions in This Issue

Results of tests into the energy efficiency of belt conveyor transportation systems indicate that the energy consumption of their drive mechanisms can be limited by lowering the main resistances in the conveyor. The main component of these resistances is represented by belt indentation rolling resistance. Limiting its value will allow for a reduction in the amount of energy consumed by the drive mechanisms. Bajda and Hardygóra [1] present a test rig which enables uncomplicated evaluations of such rolling resistances. The rolling resistance tests on the test stand, which the authors called the ”inclined plane”, can be used to search for the optimal parameters of rubber compounds and optimal design solution for belt bottom covers. The article also presents the results of comparative tests performed for five steel-cord conveyor belts. The tests involved a standard belt, a refurbished belt, and three energy-saving belts. As temperature significantly influences the values of belt indentation rolling resistance, the tests were performed in both positive and negative temperatures. The results indicate that when compared with the standard belt, the refurbished and the energy-efficient belts generate higher and lower indentation rolling resistances, respectively. In order to demonstrate practical advantages resulting from the use of energy-saving belts, this article also includes calculations of the power demand of a conveyor drive mechanism during one calendar year, as measured on a belt conveyor operated in a mine. The replacement of a standard belt with a refurbished belt generates a power demand that is higher, and with an energy-efficient belt it is lower. For this reason, the authors suggest that refurbished conveyor belts should be withdrawn from service.

Olchówka et al. [2] compares two methods of identification and classification of steel cord failures in the conveyor belt core based on an analysis of a two-dimensional image of magnetic field changes recorded using the DiagBelt system around scanned failures in the test belt. One of the aspects undertaken in this study is the statistical analysis of the obtained data, which allows determining the correlation between the input data and the class to which the damage belongs. These values were compared with the values determined for the test set. It is, however, worth noting that with such a choice of analysis for automatic recognition of damage, it is necessary to execute many damage measurements for multiple sets of parameters to obtain a sample that comes from the same distribution as the training data. This solution can be cumbersome and, as the study shows, verification by the mean of the sample data is not always reliable. In the second stage of the research, artificial intelligence methods were applied to construct a multilayer neural network (MLP) and to teach it appropriate identification of damage. The failure classification using a neural network showed high efficiency. In both methods, the same data sets were used, which made it possible to compare methods. It is worth noting that while analysis of statistical methods has already been used in the classification of belts damage, cluster analysis and analysis using the neural networks have so far been rarely discussed and their results rarely presented.

Doroszuk et al. [3] addresses the conveyor transfer station design problem in harsh operating conditions. Conditions include very slopped receiving conveyor belts, acute angle between conveyors, and demanding atmospheric conditions. The work aims to identify and eliminate a failure phenomenon that interrupts aggregate supply. The failure—blockage of the transfer station—is observed during the transfer of the high volume of the material. The analyzed transfer station is located in a Polish granite quarry "Graniczna" in Dolnośląskie Voivodship. The first stage of the study employs laser scanning of the transfer station and the feeding and receiving conveyor belts. The reverse engineering methods used the point cloud aggregated from 3D scans to map the existing transfer station and its geometry. CAD model created from the point cloud was prepared so that the geometry of the transfer station and conveyors could have been represented by flat surfaces that had contact with bulk material. Next, a discrete element method (DEM) model of granite aggregate has been prepared. The preparation of the DEM model involved parametrization of the granite from the quarry, including Young modulus, Poisson ratio, density, coefficients of restitution, and rolling and sliding friction. The tested parameters were calibrated. Using calibration box in which bulk material was flowing from the upper part to the lower part, and the angles of repose were measured as the parameter for calibration. Parameters of the simulated material in the DEM simulation of the performed experiment were changed in small ranges to obtain the repose angle with the same accuracy as in an actual experiment. The final calibrated parameters were used together with the CAD model of the transfer station to simulate the current operating conditions. The arch formation has been identified as the main reason for breakdowns. The opening of the transfer station was too narrow, and when a large number of big rocks have been falling into the transfer station at the same time, there was a higher risk of forming the arch from rocks that were blocking the opening and causing the material to accumulate in the station and cause failure. Alternative design solutions for transfer stations were tested in DEM simulations. The most uncomplicated design for manufacturing incorporated an impact plate, and a straight chute has been selected as the best solution. The selected design eliminates geometry with the opening, thus is eliminating the risk of arch formation. The study also involved identifying areas of the new station most exposed to wear phenomena. A new transfer point was implemented in the quarry and resolved the problem of blockages, and the areas most exposed to wear were covered with special liners.

Bortnowski et al. [4] deals with the issues of transverse vibrations of the conveyor belt and the description of vibrations by models. The authors reviewed the literature on vibration models in static and dynamic conditions, attention was paid to the issue of tape movement. Models describing vibrations were analyzed, comparing them to results measured in laboratory conditions. A string model and a beam model were proposed, introducing a parameter describing the movement and speed of the belt called the equivalent force in the belt. The research was performed at a laboratory station, the following parameters were controlled: linear speed and belt tension of the spacing of idler supports. For frequency measurements, the SVAN979 noise and vibration meter by Svantek ltd and the NI USB-4432 measurement system with LabView software were used. The course of the research procedure, the conditions of experiments and the procedure of data from signal registration, through spectral analysis to obtaining vibration frequencies, were discussed. The results are presented in tabular form and on graphs, which allows the authors to assess the impact of individual parameters on the measured frequencies. In the next section, the calculation results were compared based on the proposed models with the measured frequencies. The results are compiled on a graph, where you can see which of the models better reflects reality, and that the spacing of the idlers can have a large impact on the frequencies obtained. The MAE was calculated for the string model and the beam model, the trend was set in the function of the spacing of the idler supports. The results show that for small spacing, smaller than 1.6 m, the measured frequency is better presented by the beam model. For spacing larger than 1.6 m, the string model becomes more optimal. The beam model is therefore more applicable in vibration analyses in the upper belt, while the string model is more applicable in vibration analyses in the return belt.

The aim of the experimental studies presented by Marasova et al. [5] was to investigate and compare the dynamic loading of a P2500 type textile-rubber conveyor belt. The dynamic loads occurred when the belt was struck by a specially designed punch, which simulated the impact of excavated material on the belt. A comparison was made between the relative energy absorption values obtained with and without the use of the belt support system. The experiments simulated various real-life conditions such as impact of materials with different masses and impact from different heights. On the basis of the conducted research, a model of the dependence of the relative amount of absorbed energy on selected parameters was created. Some parameters of the impact process were taken into account in the proposed dynamic model. The obtained regression model confirmed that the mass of the punch hitting the belt and the presence of the belt support system are the parameters having statistically significant effect on the amount of energy absorbed by the belt during the impact of the striker against it.

Dąbek et al. [6] presented automated methods of industrial inspection are becoming more popular each day, not only in the inspection of products, but also very demanding task of inspecting the workplace in search of any signs of damage to the equipment or safety related problems. Regarding this aspect, mines are no different from any other industrial facility, and new technologies emerge every day to keep people safe and to keep the production on track. Inspection tasks can be usually divided into several different, smaller problems that can be solved separately. One of them is the detection of faulty idlers—passive elements of a conveyor belt that allow for an extracted material to be automatically transported horizontally over long distances. Transportation process in mines can take place under unhealthy or even unsafe conditions for maintenance staff, therefore use of mobile robots, such as unmanned ground vehicles (UGV), is helpful in minimizing risks that have to be taken to keep the production going. Data collected from sensors mounted on proposed robots can have many forms, such as 3D scans, noise or image recording, just to name a few. In this case, infrared images were used in order to detect the faulty idlers, as they generate heat due to friction coming either from the damage of the internal bearing, or from the friction between the belt and the idler when the idler is completely stuck and does not rotate. The process is supported by pre-processing performed on the RGB images, that allows to focus on the belt conveyor by excluding the unnecessary parts of the video, that may contain noise affecting the results of implemented algorithm. The experiment has been performed on dataset collected in real industrial conditions by UGV, where the proposed algorithm has proven to be effective.

In mining industry, both surface and underground, belt conveyors are widely used for the horizontal transportation of materials. Automated inspection of such structure, especially from the point of view of the inspection of idlers, is a very complex problem, especially due to three aspects. The first problem is scale—it is difficult to measure every parameter at every point when the length of the conveyor can in some cases exceed 1 km. The second problem is accessibility—it is impossible to place sensors in every place that one would like to, especially for our case, it is impossible to put vibration sensors directly on the bearing of an idler. The third problem is environmental accessibility—especially in underground mining the environmental conditions (temperature, humidity, dustiness, etc.) do not allow for prolonged inspection activities performed by human, especially with a lot of measurement equipment that they would have to carry around. To address those issues, Shiri et al. [7] propose to use an inspection robot that (besides other functionality) is able to record acoustic signals. Using a mobile robot (either remotely driven or autonomous) can largely improve safety of the inspection tasks, as well as accuracy and repeatability of the data acquisition itself. Acoustic data analysis is already widely used in condition monitoring. The robot can record a short segment of acoustic signal next to each idler. Then, signal processing techniques are used for signal pre-processing and analysis to check the condition of the idler. The authors have determined that even if it is possible to identify the damage signature in such signal, there is a lot of disturbances, such as random noises or belt joint passing over the idlers. In such case, classical signal processing techniques cannot be used, and very often they indicate a fault even if a given idler is in a good condition. In this paper. the authors propose novel processing solutions that allow for proper analysis of the acquired signals.

The selection of a conveyor belt capable of performing a particular transportation task when installed on a belt conveyor is primarily informed by the tensile strength of this belt. It is intended to ensure that the forces in the operating belt will not lead to it breaking, i.e., to an event that is dangerous to both the personnel and to the conveyor. Typically, in the belt conveyor design process, the values of safety factors are empirically identified. Breaks in the so-called "continuous" (unspliced) belt sections, and not in the spliced areas, are infrequent but do happen in practice. Woźniak and Hardygóra [8] present some aspects that may account for such breaks in conveyor belts. It indicates the so-called "sensitive points" in design, especially in the transition section of the conveyor belt and in identifying the actual strength of the belt. The presented results include the influence of the width of a belt specimen on the identified belt tensile strength. An increase in the specimen width entails a decrease in the belt strength. The research involved develops in universal theoretical model of the belt on a transition section of a troughed conveyor in which, in the case of steel-cord belts, the belt is composed of cords and layers of rubber, and in the case of a textile belt, of narrow strips. The article also describes geometrical forces in the transition section of the belt and an illustrative analysis of loads acting on the belt. Attention was also devoted to the influence of the belt type on the non-uniform character of loads in the transition section of the conveyor. The transition section of the conveyor is a region in which the forces in the belt cross-section vary significantly. Such non-uniformity of belt loads was confirmed in the analysis performed with the use of an original theoretical model of the belt in the transition section of the troughed conveyor, which allows for the elastic properties of the belt and for the interaction with adjacent cables/strips. The lowest load non-uniformity was observed in the belt with multi-ply polyamide core, and higher values—in belts with polyester–polyamide cores, with solid woven cores, with aramid cores, and with steel-cord cores, respectively. When replacing a worn belt, each decision to change the belt type should be preceded by a new analysis of the geometrical parameters of the transition section in the belt conveyor In the case when the operator decides to install a belt having different elastic properties but without modifying the geometrical parameters of the transition section, the belt load nonuniformity may be increased by as much as several hundred percent. This fact is of special importance in the case of the transition section before the drive pulley, where typically, the highest force levels in the belt are observed.

3. Conclusions

The need for investigations into lower energy consumption of belt conveyor drive mechanisms is demonstrated most importantly, by the popularity of belt conveyors in the global mining industry. The articles presented in this Special Issue have created a set of solutions that may be of interest to researchers dealing with the energy efficiency of belt conveyors in mine transport. The material is also a source of information for those who deal with conveyor transport on a daily basis.

The solutions presented in the Special Issue have an impact on optimizing and thus reducing the costs of energy consumption by belt conveyors. This is due, inter alia, to the use of better materials for conveyor belts, which reduce its rolling resistance and noise, and also improve the ability to adsorb the impact energy coming from the material falling on the belt. The use of mobile robots designed to detect defects in the conveyor's components makes the conveyor operation safer and the conveyor works longer and there are no unplanned stops due to damage.

Further development of conveyor transport should aim at greater reduction of electric energy consumption by conveyor drives. Solutions presented in the discussed articles lead to this goal.

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