An Effective Belt Conveyor for Underground Ore Transportation Systems

Robert Krol¹, Witold Kawalec¹, Lech Gladysiewicz¹

¹ Faculty of Geoengineering, Mining and Geology, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

witold.kawalec@pwr.edu.pl

Abstract. Raw material transportation generates a substantial share of costs in the mining industry. Mining companies are therefore determined to improve the effectiveness of their transportation system, focusing on solutions that increase both its energy efficiency and reliability while keeping maintenance costs low. In the underground copper ore operations in Poland’s KGHM mines vast and complex belt conveyor systems have been used for horizontal haulage of the run-of-mine ore from mining departments to shafts. Basing upon a long-time experience in the field of analysing, testing, designing and computing of belt conveyor equipment with regard to specific operational conditions, the improvements to the standard design of an underground belt conveyor for ore transportation have been proposed. As the key elements of a belt conveyor, the energy-efficient conveyor belt and optimised carrying idlers have been developed for the new generation of underground conveyors. The proposed solutions were tested individually on the specially constructed test stands in the laboratory and in the experimental belt conveyor that was built up with the use of prototype parts and commissioned for the regular ore haulage in a mining department in the KGHM underground mine “Lubin”. Its work was monitored and the recorded operational parameters (loadings, stresses and strains, energy dissipation, belt tracking) were compared with those previously collected on a reference (standard) conveyor. These in-situ measurements have proved that the proposed solutions will return with significant energy savings and lower maintenance costs. Calculations made on the basis of measurement results in the specialized belt conveyor designing software allow to estimate the possible savings if the modernized conveyors supersede the standard ones in a large belt conveying system.

1. Introduction

Technological processes in the mining industry include various raw material transportation operations which consume significant amounts of energy and generate a substantial share of overall mining costs. The biggest savings can be achieved as a result of optimized mine planning and design [1] but an existing transportation system in a mine can still be improved to match growing needs of reducing specific transportation costs and decreasing the generated CO₂ emission. However, neither energy efficiency nor costs savings should prevail the requirements of reliability and sufficient capacity of any mining transportation system. In the underground mines – due to safety reasons and relatively difficult conditions of a transportation machinery equipment maintenance – well proven, standardized and oversized machines are usually preferred by technicians. An introduction of a new solution has to...
be preceded with the passed comprehensive tests which ensure that all safety and technological requirements have been matched.

The transport systems used in the KGHM underground copper ore mines were chosen and designed for the room and pillar mining system [2]. The characteristic feature of the horizontal transport in all three KGHM mines is the use, at the various stages and on a different scale, of both cyclic transport (LHDs, trucks and rail transport) and the high-capacity continuous transport (belt conveyors - BC). The total length of underground belt conveyor routes exceeds 165 km. Approximately 2/3 of all conveyors are installed in the mining panels to support the division haulage where they are directly loaded by LHDs and trucks. The remaining conveyors work in the main transportation routes. These conveyors collect the ore from several division conveyors and deliver it to the shafts bunkers.

The main goal of managing the BC systems in KGHM underground mines is to maintain the high level of the total output of ore supply. The firm requirement of mining divisions is to avoid delays of discharging mining trucks and LHDs because of any stoppages of the BCs. Such delays result in decrease the number of trucks’ courses – less ore is then hauled from a mining panel. The BCs that receive ore from the cyclical transport are therefore generally expected to run throughout the whole working period of a shift. Though there are numerous ore bunkers (see Figure 1) their full capacity is needed to allow on any unpredicted stoppages of BCs without holding the ore delivery from mining panels.

![Figure 1](image)

**Figure 1** A schematic overview of the selected branch of the belt conveyor transportation system in the KGHM Lubin mine (Source: Lubin Mine)

The idle work of BCs in the underground ore transportation is the result of putting the high output of mining panels on the top of the priority list. Therefore, in order to achieve the significant energy savings of conveying the ore in the underground BC system, the efforts should be put into the decrease of specific energy consumption of BCs by the lowering their idle work energy consumption. This can be achieved by an improvement of BC design aiming the low energy consumption. This goal can be achieved due to [3,4,5]:

- careful choice of a conveyor belt, with special regard to rubber mix parameters, selected individually for the planned operational conditions at the users’ site,
- modernised idlers with reduced rotational resistance to motion,
- precise dimensioning of a conveyor units (which requires the use of advanced, computer assisted design tools).
The only possible way of the successful improvement of the elements of a BC designed to work in the harsh operational environment of underground mines is the extensive support of in-situ tests combined with the accurate calculations of the BC drive power requirements with regard to alternative BC equipment selection [3]. The applied solution is described below.

2. Solutions for underground belt conveyors for transporting ore
Theoretical and experimental (performed in the laboratory premises and in-situ) investigations in the field of heavy duty mining belt conveyors main resistances to motion have been carried out for many years [6,7,8]. The basis of the research that has been carried out in the Faculty of Geoengineering, Mining and Geology at the Wroclaw University of Science and Technology is the analysis of the energy dissipation processes in a conveyor belt and in the material load stream and the analysis of the interaction between the belt and idlers [9]. These processes depend on a large set of technical, physical and operational data of a belt, transported bulk material, design characteristics of a conveyor and the conditions of the use of the conveyor [7]. Physical properties of the belt and bulk material and the geometry of the conveyor have been employed in the algorithm to identify main resistance of a belt conveyor: idler rolls turning resistance, indentation resistance, flexure resistance of a belt and bulk material and sliding resistance of a belt on idlers.

The knowledge of use and maintenance of large transportation systems is supported by information [11] and diagnostic [12] systems which monitor and analyze the operational data recorded from running belt conveyors. The obtained results help to select the technical improvements in the belt conveyor equipment which should bring required energy and costs savings while retaining reliability and safety of the standard underground belt conveyors.

The investigations of the effective underground belt conveyor for cooper ore transportation consisted of three key elements:

- Identification of the operational conditions of belt conveyors in the underground transportation system – distribution of loading, typical conveyor route length and lift, operational hazards, use of simulation models [13].
- Laboratory tests of the pre-selected solutions of improved belts [14] and idlers [15] for choosing the preferred ones and comprehensive in-situ tests of proposed solutions [16,17].
- Development of calculation methods of belt conveyor resistance to motion with regard to individual characteristics of improved equipment and recognized operational conditions of underground belt conveyor transportation systems [18].

The parameters of the investigated belt conveyors (both tested in-situ and calculated on the basis on their actual or optionally assumed parameters) are presented in table 1.

### Table 1. Selected parameters of analyzed underground conveyors.

| Parameter                                   | value                                                                 |
|---------------------------------------------|----------------------------------------------------------------------|
| Transported output, density, kg/m³          | Copper ore, 1700                                                     |
| Ambient temperature, °C                     | 25                                                                  |
| Length, m; route inclination                 | 500, 700, 1500; horizontal                                          |
| Belt width, mm                              | 1000                                                                |
| Belt; covers thickness, mm                  | Slow-burning, EP2000/4 6+3 or 1000 ST 2000 8+6                      |
| Belt speed, m/s                             | 2, 2.3                                                              |
| Spacing of carry idlers, m                  | Variants: 0.83; 1.25; 1.66 (used: 0.83)                             |
| Rotation resistance of upper idler, N        | According to quoted characteristics                                  |
| Actual output for calculations, t/h         | 0, 200-1400                                                         |
| Belt tension arrangement                     | Adjusted for maximum load                                           |
2.1. Improved conveyor belt

Improvements of belt conveyor equipment were focused on decreasing the idler rotational resistance and the indentation resistance which together share up to 70% of the total resistance force of a belt conveyor [7,9]. Following the theoretical analysis, the indentation resistance depends on two parameters of a belt: the damping factor of belt subjected to cyclic compression and the elementary transverse flexural rigidity [5,6]. The proper choice of material chosen for rubber bottom covers of a belt can significantly decrease the indentation resistance.

The properties of various rubber mixes were investigated on a special test rig in a climatic chamber where the operating conditions of a belt have been simulated by cyclic pressing [17]. Characteristics and parameters identified in the laboratory were then implemented into the computational model of a belt conveyor [18]. Basing upon them and the recognized operational conditions of underground belt conveyors, the specific energy consumption (an amount of energy needed for moving 1 kg of conveyed ore for a horizontal distance of 1 m) of a main haulage belt conveyor has been calculated (table 2). In the table several new, energy efficient conveyor belts with innovative rubber mixes (B..D) were analyzed and compared with the standard one – belt A. The belt B was chosen for the further tests and eventually implemented in the effective belt conveyor.

| Type of the conveyor belt (A-standard belt) | Specific energy consumption on a BC (L=1500m) [Ws/kgm] | Specific energy consumption in top belt strand on a BC [Ws/kgm] |
|------------------------------------------|---------------------------------|---------------------------------|
| A                                       | 0.455                           | 0.302                           |
| B                                       | 0.372                           | 0.239                           |
| B+                                      | 0.399                           | 0.253                           |
| C                                       | 0.422                           | 0.274                           |
| D                                       | 0.396                           | 0.275                           |

The obtained almost 20% savings of the specific energy consumption was obtained for the given belt conveyor operating parameters (distribution of loading, length, ambient temperature) and does not imply that such result would be repeated for other belt conveyor arrangements. Instead, series of calculations compared with in-situ results have proved that the operational conditions (especially the actual distribution of loading and the occurrence of an idle mode throughout its working time) can increase or decrease the actual savings of energy used by a BC.

2.2. Improved carrying idlers

Idler roller is an example of a product which looks simply but, due to harsh operational conditions and conflict requirements (low rotational resistance and lightweight design vs. durability), have to be carefully designed and tested to become a reliable equipment of a belt conveyor. Operational conditions in the underground ore mine with its aggressive moisture, dust and occurrence of big ore lumps hitting the idlers through a belt are a true challenge for mining equipment suppliers.

For the development of the new generation of energy efficient and durable idlers for underground operations a comprehensive designing and testing project was introduced [10,15,16]. Following laboratory tests [15], selected idlers solutions were installed on the experimental belt conveyor in the Lubin mine (see: figure 1). Long-time in-situ measurements [16] provided reliable results that proved the effectiveness of the solution. Improvements were done to the design of a single roll, bearings seal, lubrication and the layout of the whole idler (a suspended idler set was replaced with a rigidly mounted one). Chart on figure 2 shows the obtained reduction of a rotational carrying idler resistance to motion.
Rigidly mounted idlers help to avoid the sliding resistance (caused by a horizontal skew of side rollers) which has a positive impact on the symmetrical loading of side rollers. Any differences between vertical forces on side rollers mean that one of them can be easily overloaded which shorten its life significantly (see: figure 3).

The calculations, made on the basis of measurement results [10] shown that carrying idler spacing which has retained its conservative value of 0.83m can be extended to 1.25 at least for the division haulage conveyors without loss of their durability. Such layout has not been tested in-situ yet.

2.3. Combined results
The selected and tested improvements of the energy efficient steel-cord conveyor belt and new carrying idlers were eventually implemented in the experimental belt conveyor, which was then monitored over a long time with the help of specially built measuring stand [16]. Resistances to motion were recorded against a wide range of loadings and compared with the measurement results obtained from a standard conveyor. The comparison is presented on figure 3.
Figure 4. A comparison of measured resistances to motion of the standard (top line) and the effective (bottom line) BC against the actual capacity.

The obtained result is promising and have proved that the selected solutions had matched the expectations. The experimental belt conveyor is operating in a harsh condition in the typical mining panel. It has to be underlined hat the tested improvements do not require any major refurbishments of the existing equipment. Conveyor belt and idlers are replaced due to their normal wear and the can the standard elements can be superseded by the effective ones.

3. Expected savings for underground ore transportation systems
The replacement of the standard underground belt conveyors equipment with the effective one is feasible but the company needs to know whether it could be profitable. The measurement results (supported by calculations) of resistances to motion have to be converted into figures that represent amount of consumed energy by belt conveying during average operation.

The possible savings in the selected branch of the transportation system of the Lubin mine (figure 1) have been computed on the basis of exact length of division and main haulage conveyors. The division conveyors operate approximately 4000 hours per annum at the average capacity of 192 t/h. The main haulage conveyors operate much longer (some 6000 hours per annum) and their average capacity is also higher and reach some 834 t/h. The specific energy consumption was calculated for the whole range of loading the conveyors with the transported ore and the values in the 4th column in the table 3 are averages weighted against the distribution of transported ore stream mass recorded for the division and main haulage conveyors [10]. High value of a specific energy consumption for division belt conveyors is caused by the fact, that some 30% of their working time is occupied by the idle mode. As mentioned above it cannot be easily avoided due to mining reasons.

Estimated energy cost does not include various elements of electric energy bills and various tariffs that apply for the energy consumed in day and night.
Table 3. Annual energy uses in the chosen branch of the mine transportation system computed for standard and effective BC used for division (total length 11.9 km) and main (7.7 km) haulage area (assumed 4000 and 6000 working hours respectively) of operation) conveyor.

| Haulage area | BC type  | Average capacity [t/h] | Specific energy consumption on a BC [Ws/kgm] | Annual energy consumption on a BC [kWh/m] | Total annual energy use [MWh] | Estimated annual energy cost (at 60 €/MWh) [thous. €] |
|--------------|----------|------------------------|---------------------------------------------|------------------------------------------|------------------------------|-----------------------------------------------------|
| Division     | standard | 192                    | 1.705                                       | 364                                      | 4320                         | 260                                                 |
|              | effective| 192                    | 0.92                                        | 197                                      | 2330                         | 140                                                 |
|              | savings  | 192                    | 0.78                                        | 167                                      | 1990                         | 120                                                 |
|              | **savings** | **192** | **0.78** | **167** | **1990** | **120** |
| Main         | standard | 834                    | 0.48                                        | 667                                      | 5182                         | 311                                                 |
|              | effective| 834                    | 0.234                                       | 326                                      | 2530                         | 152                                                 |
|              | savings  | 834                    | 0.245                                       | 341                                      | 2652                         | 159                                                 |

The presented assessment shows that the savings in electric energy bills can reach up to 0.3 million euro for the analyzed branch alone. The savings of energy and energy costs for the all KGHM underground mines are presented in table 4. These estimations are less accurate as the total length of belt conveyors has been roughly divided into 75% of the division and 25% of the main haulage transport. The weighted annual energy consumption savings are then multiplied by the total length of belt conveyor routes in each mine and in the whole KGHM company.

Table 4. Expected savings of energy use in the KGHM mines transportation systems after the full introduction of effective BC (for the calculations assumed 210.5 kWh/m of annual averaged energy consumption savings on a BC, weighted upon the typical share of 75% of division transport and 25% of a main transport in the total length of BC routes).

| Mine     | Total length of the BC system [m] | Expected annual energy consumption savings [MWh] | Estimated annual energy cost savings (at 60 €/MWh) [million €] |
|----------|-----------------------------------|-------------------------------------------------|------------------------------------------------------------|
| Rudna    | 51185                             | 10 774                                         | 0.646                                                      |
| Lubin    | 40185                             | 8 459                                          | 0.508                                                      |
| Sier-Pol | 75755                             | 15 946                                         | 0.957                                                      |
| Total    | 167125                            | 35 180                                         | 2.111                                                      |

Estimated number of 35 GWh of saved energy due to modernization of underground belt conveyors is a substantial saving which should promote the proposed improvements. More savings to the estimated for the effective belt conveyor are available due to: optimized idlers spacing [10] and avoiding an idle mode (when possible).

4. Conclusions
The technical improvements of the standard underground belt conveyor for transporting copper ore consisting of the energy-efficient conveyor belt and optimised carrying idlers have been developed for the new generation of underground conveyors.

The proposed solutions were comprehensively tested in the laboratory and on the experimental belt conveyor that was built in the mining panel of the KGHM Lubin mine to serve the mining operations. Long-term durability tests were also applied to ensure the mine management that the new, energy efficient equipment will not fail requirements of the operating time.

The measurement results were also implemented (as specific equipment characteristics) in the exact methods of calculation the belt conveyor resistances to motion. Calculations were used for both investigating the operational parameters of the modernized belt conveyors and for the assessment of possible energy and costs savings after the implementation of the efficient belt conveyor in the
underground transportation systems in the KGHM mines. Approximately 35 GWh of electric energy and above 2 million euro of energy costs can be saved.

Such significant reduction of consumed energy not only means lower direct bills for electric energy but also helps the company to avoid additional expenses on “carbon” limits. Any energy efficient improvements create “more green” face of a mining company which is important for its public image regardless on the real technical achievements.

Acknowledgment(s)
This paper was financially supported partly by the Polish Ministry of Science and Higher Education as scientific project No 0401/0166/16.

References
[1] T.D. Lee, “Planning and mine feasibility study – An owner perspective”. In: Proceedings of the 1984 NWMA Short Course „Mine Feasibility –Concept to Completion”. (G.E. McKelvey, compiler) Spokane, WA, 1984.
[2] M. Hardygóra, L. Gladysiewicz, “Analysis Of Transportation Systems In Polish Mining Industry”, Proceedings of 12th International Symposium on MPES 2003, Kalgoorlie, Western Australia, 2003.
[3] L. Gladysiewicz, W. Kawalec, “Energy saving solutions for belt conveying”. Proceedings of the Eleventh International Symposium on Mine Planning and Equipment Selection, Bouzov, Czech Republic, 9-11 September 2002, VSB – Technical University of Ostrava, 2002.
[4] G. Lodewijks, “The next generation low loss conveyor belts”, Bulk Solids Handling 32 (1):52-56, January 2012.
[5] J. I. O’Shea, C. A. Wheeler, P. J. Munzenberger, D. G. Ausling, “The Influence of Viscoelastic Property Measurements on the Predicted Rolling Resistance of Belt Conveyors”, J. Appl. Polym. Sci. 2014.
[6] G. Lodewijks G., “The rolling resistance of conveyor belts”. Bulk Solids Handling, Volume 15, Number 1, January/March. 1995.
[7] L. Gladysiewicz, “Belt conveyors. Theory and calculations”, Wroclaw University of Technology Publishing House, Wroclaw (in Polish), 2003.
[8] L. Gladysiewicz, M. Hardygóra, W. Kawalec, “Determining belt resistance”. Bulk Handling Today, No.5, 2009.
[9] L. Gladysiewicz, W. Kawalec, “The possibilities of decreasing the belt conveyors main drive power demand”, Proceedings of the Conference Bulk Europe 2008, Prague, 2008.
[10] L. Gladysiewicz, W. Kawalec, R. Król, “Selection of carry idlers spacing of belt conveyor taking into account random stream of transported bulk material”. Eksploatacja i Niezawodność - Maintenance and Reliability, vol. 18, nr 1, pp. 32-37, 2016.
[11] M. Kacprzak, P. Kulinowski, D. Wędrzychowicz, "Computerized information system used for management of mining belt conveyors operation", Eksploatacja i Niezawodność - Maintenance and Reliability, 2/2011 s 81-93. 2011.
[12] M. Bajda, R. Błażej, L. Jurdziak, A. Kirjanov, „Condition monitoring of textile belts in the light of research results of their resistance to punctures investigations”. 16th International Multidisciplinary Scientific Geoconference (SGEM 2016): Alba, Bulgaria, 30 June – 6 July, 2016, vol. 2, Exploration and mining, mineral processing, 2016. art. pp. 165-172, 2016.
[13] P. Kulinowski, “Simulation studies as the part of an integrated design process dealing with belt conveyor operation”, Eksploatacja i Niezawodność - Maintenance and Reliability 2013, vol. 15 nr.1 s. 83-88. 2013
[14] M. Bajda, R. Błażej, M. Hardygóra, “Impact of selected parameters on the fatigue strength of splices on multiply textile conveyor belts”, World Multidisciplinary Earth Sciences Symposium (WMESS 2016): 5-9 September 2016, Prague, Czech Republic. IOP Publishing, 2016. art. 052021, pp. 1-6. 2016.
R. Król, W. Kisielewski, D. Kaszuba, L. Gładysiewicz, “Laboratory tests of idlers rotational resistance - selected issues”. Procedia: Earth and Planetary Science 2015, vol. 15, s. 712-719, World Multidisciplinary Earth Sciences Symposium, WMESS. 2015.

R. Król, W. Kisielewski, D. Kaszuba, L. Gładysiewicz, “Testing belt conveyor resistance to motion in underground mine conditions”. International Journal of Mining Reclamation and Environment. 2017, vol. 31, pp. 78-90, 2017.

M. Bajda, R. Król, “Experimental tests of selected constituents of movement resistance of the belt conveyors used in the underground mining”. Procedia: Earth and Planetary Science 2015, vol. 15, s. 702-711, World Multidisciplinary Earth Sciences Symposium, 2015.

W. Kawalec, P. Kulinowski, Computations of belt conveyors. Transport Przemysłowy 1(27), 2007 (in Polish)