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LABORATORY TESTS ON E-PELLETS EFFECTIVENESS FOR ORE TRACKING

Ryszard BŁAŻEJ, Witold KAWALEC*,
Martyna KONIECZNA, Robert KRÓL

Faculty of Geoengineering, Mining and Geology, Wrocław University of Science and Technology, Poland

Abstract: Assigning transported material with a supplementary information is becoming relevant for the needs of improving the efficiency of industrial processes. In the mining industry annotating the mined ore could bring benefits due to expected decrease of the processing energy consumption and increase of productivity. DISIRE project was focused on the implementation of e-pellets for various raw material processing and transportation processes. The paper presents laboratory tests of alternative RFID equipment for annotating ore with marked tags. Several aspects of tags traceability were investigated for the needs of the industrial tests that were eventually done in the underground mine environment. The laboratory tests results were compared with the similar tests described in the literature, that were done in the different conditions.

Keywords: *RFID tag, ore tracking, DISIRE, laboratory tests, belt conveyor, traceability*

1. INTRODUCTION

Mining companies look for increase of their efficiency by saving the energy consumed throughout a whole mine production value chain (aiming for both cutting costs and lowering the carbon footprint) and by rising productivity and improving of the quality of products. Computerization of mining works helps to gather more information from mining operations and thus identify key parameters of the mine value chain. In the current stage of knowledge more attention is paid to tracking (or

Corresponding author: witold.kawalec@pwr.edu.pl (W. Kawalec)

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tracing – no precise definitions are acknowledged) the operations. Therefore traceability, understood as "the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales or internally in one of the steps in the chain" (Moe 1998; cited by Kvarnstrom 2010) is widely investigated for the needs of the industry. First steps in the development were made and nowadays systems of tracking machines, people and material are used in many applications for versatile purposes.

For positioning of transported items, the typical choice of technology is passive RFID – Radio Frequency Identification (Kvarnström & Vanhatalo 2010). In this technology, passive transponders (called also tags or e-pellets) use energy supplied by a reader antenna to power the internal electronics. Tags are added to the material at selected points of the transportation chain. They are then detected when required by the use of antennas installed around or over the process flow. Passive RFID tags compared to the active (battery powered) ones are low cost and their ability to be read do not decrease with time. While for packaged goods the ultra-high frequency (UHF) passive RFID are used to achieve long detection range, for detection through mineral products that exhibit high attenuation at higher frequencies, the low frequency (LF) passive RFID are preferred.

In (Kvarnstrom 2010) various traceability aspects are discussed, especially for the needs of tracking of continuous ore flow. There are companies, which specialize in use RFID tags for tracking staff (Pyszniak 2014). Tracking vehicles with RFID tags to avoid collisions is commonly used in Australia mines. Identification and annotating with a tag a single item of a product (separated from the others) and a batch (or: lot) of such products (e.g. a container, a palette) is clear, this is not obvious in a case of any unpackaged bulk material which is supplied continuously. "Batches do not exist in continuous processes, so using batch structures for achieving traceability is difficult. Creating virtual batches by dropping some type of marker in the material flow with regular intervals would, however, make it possible to use the batch technique for achieving traceability" (Kvarnstrom & Oghazi 2008). Such approach has already been implemented in the mineral industry. In Sudbury Basin mined material is tracking to predict which type of ore will be extracted and to provide the information how much time it will take to get mined ore to the surface (Roberti 2013). Another example comes from South Africa where in few gold mines RFID tags help workers to distinguish golden ore and waste and identify where the material has come from (Swedberg 2008). This solution still needs people involved; tags are numbered by hand-writing and to classify the material a worker reads an ID number of each tag and compares it with the list of all ID's. Other applications of RFID tags implemented to improve mining and processing of metal ore and aggregates are described in (Jansen et al. 2009; Rabe et al. 2005; Wortley et al. 2011).

The balance copper ore seam exploited by the Polish KGHM S.A. underground mines is considered as one of the most difficult to be processed. The ore consists of three lithology forms: dolomites, shales and sandstones (Pactwa & Malewski 2013) but in changing proportions. As the actual ore compound has a significant impact on the effectiveness of the grinding and flotation processes, its identification on the entrance to the processing plant would be important for the whole copper production value chain. Actually the local ore compound is recognized *in-situ* – at mining faces but after being blasted from the balance seam the succeeding batches of mined ore are mixed in the complex transportation system consisting of conveyors and ore bunkers. The final ore mixture compound is unknown. If each batch of ore loaded onto conveyors is annotated with a tag containing the relevant information, necessary to identify its compound and the tags are read prior to the moment when ore batches reach the processing plant ((Jurdziak & Król & Kawalec 2017)) then an assessment of the resulting copper ore batch compound could be done in order to tune up the processing machinery.

To create an efficient system for identifying the ore stream first theoretical investigations and laboratory measurements should be made. Project DISIRE Horizon 2020 was launched in order to create intelligent ore tracking system with RFID sensor and tags (DISIRE 2018). The project would become irrelevant in the case that in the real operating conditions of an underground mining transportation system the proposed DISIRE solution simply does not work. Therefore the in-situ tests, performed with regard to existing technological and formal constraints and threads were considered as the key element of the DISIRE project. Though various experimental works in the underground mines had been well practiced by the DISIRE project group from the Wroclaw University of Science and Technology (Król et al. 2017), the preliminary laboratory tests of the use of RFID tags for annotating the copper ore were acknowledged as a compulsory step to prepare the industrial tests.

2. SUBJECT OF STUDY

The purpose of the experiment in laboratory was to check how tracking the cooper ore with RFID tags works. In the experimental phase of the project two measuring sets of equipment have been used. Each one contained a reader, an antenna and RFID sensors (tags) suitable for this equipment. Equipment 1 (completed at the Wroclaw University of Science and Technology) and equipment 2 (supplied by DISIRE Project partner – the Swedish Electrotech company) are presented in figure 1. The equipment 1 was selected for the laboratory tests from the industry standard RFID solutions (working at the bound 867–869 MHz) that are widely available on the market for logistic technology. Such solution provides no troubles in terms of supply and maintenance at low cost. The selection of the system was focused on tags parameters. A tag should be relatively small (in reference to the average ore particle size) but durable and shock resistant (Fig. 2).

Each selected reader can recognise its own RFID tags. For the equipment 1 only one type of tags (Fig. 2 left) was available. For the equipment 2 there were two types of tags (Fig. 2 right), so the each experiment was done twice. Tags from equipment 2 were labelled – each with its own ID – in order to control easily the recognition of particular pellets by the reader. The labelling was of great value for the later tests in the mine and enabled to gain the needed flexibility of positioning of several dropping point of tags during the in-situ tests.

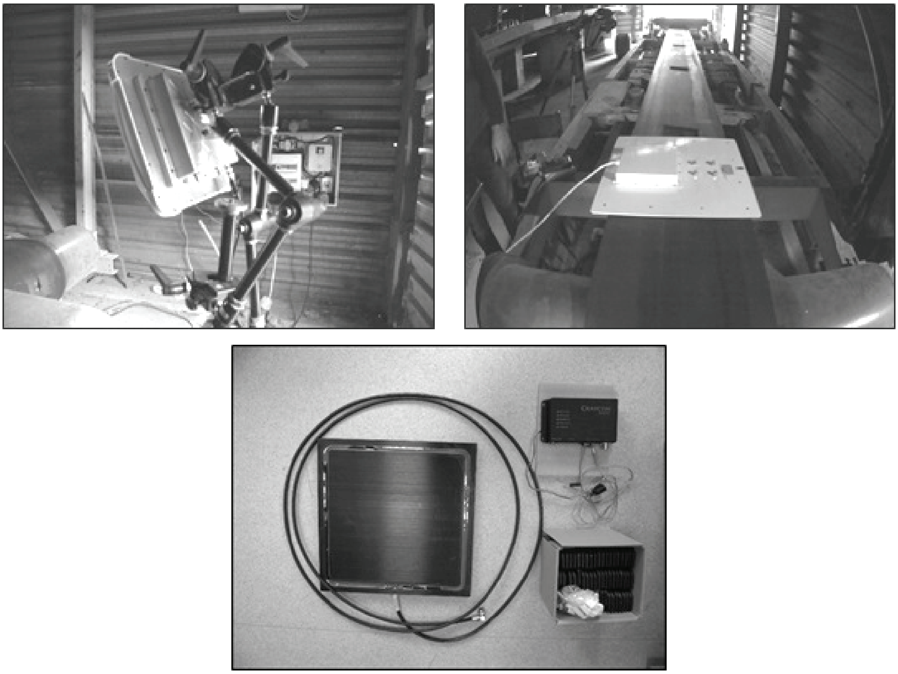

Fig. 1. Top: equipment 1 – industrial antenna and reader, bottom: equipment 2 – laboratory antenna, the reader and the box of pellets (supplied by Electrotech)

Fig. 2. E-pellets prepared for the experiment: left: Equipment 1, right: Equipment 2 – pellets from Electrotech: "small", tubular (length 40 mm, diameter: 10 mm) and "big", hexagonal (length: 75 mm, width: 55 mm, thickness: 10 mm); labels on tags are their written ID (for easier checking the test results)

3. RESEARCH METHODOLOGY

The experiment in laboratory conditions was carried out on the test stand in the Faculty of Geoingineering, Mining and Geology at Wroclaw University of Science and Technology. Tests were made for two types of equipment. Experiment was conducted in many different variants in order to investigate the relation between quality of measurements (readability of tags) and conveyor work parameters.

3.1. TEST STAND – THE BELT CONVEYOR

Laboratory tests were carried out on test stand originally made for investigation of diagnostic of conveyor belt (Błażej, Jurdziak & Zimroz 2013). This belt conveyor can be used for various investigations, like in the case – for analysing tags moving with material from dropping point to the end of conveyor and if the measurement system reads them correctly. In the laboratory conveyor alternative variants of equipment installation (see Fig. 3) and tuning the parameters were investigated. Moreover the authors checked how RFID tags are sensitive to shock and sharp rocks, and finally how sensitive is the measurement system itself. This phase was the know-how building process to mitigate possible problems and unrecognized issues that could occur during the final, industrial experiment.

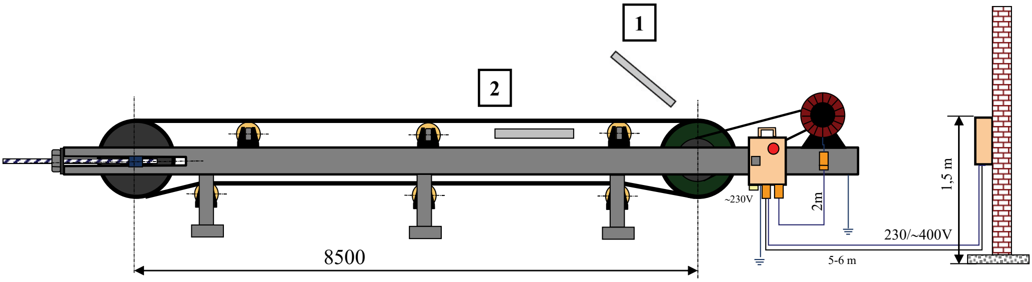

Fig. 3. Laboratory belt conveyor for testing e-pellets; investigated positioning of sensors for reading tags: above the belt (annotated by 1) and below the belt (annotated by 2) is presented

Test stand presented in the Fig. 3 has supporting structure with carrying and returning idlers, belt, head pulley and drive, take-up pulley and tensor. On this stand both textile and steel cord belts can be tested. It gives a possibility to examine all types of belts that are used on conveyors in open pit and underground mines. The test stand is almost 10 m long and the belt loop has 16 700 mm length. The stand is 1370 mm wide and 1002 mm high. During the measurements the steel-cord conveyor belt St 1600 and 400 mm wide was installed. Steel-cord belt carcass can interfere the signals transmitted to and from RFID tags, which can also occur in a mine.

The test stand is powered from 230 V net from the power box. Speed range of belt on the conveyor is from 0 to 7.5 m/s that covers all typical conveyor applications in the mining industry.

3.2. VARIANTS OF MEASUREMENTS

Experiment was carried in many different variants. It is important to model the whole process the way it looks like in the real operating conditions in an underground mine. First considered issue was the number of pellets simultaneously read. Test were carried for 1, 3 or 5 tags inside the batch of a bulk material. Another factor was the thickness of ore layer covering pellets. For the experiment the crushed cooper ore from the underground mine was used. The measurements were repeated with bare (without ore) tags or wrapped by an 0.10 or 0.20 m of the ore layer in a bucket. The last parameter was belt speed. For each case the belt speed: 1, 3 and 5 m/s were tested. During measurements each variable was checked several times to check all combinations of investigated factors. The most difficult variant was – as expected – the one with the group of tags covered by the biggest amount of ore and the highest belt speed.

Each variant was carried out with the use of two types of equipment and repeated five times for each of them. Equipment 1 was also tested against different location of the reading antenna installed relative to the belt (under and above). For the equipment 2 two types of pellets were tested. During the transport process in a mine pellets will change the position relative to belt and sensor many times. There were two main way of tags positions: vertical and horizontal. For these two options there were different variants. Pellets could be located across or along the belt or diagonally. For the diagonal location the angle about 30–45° was checked. In Figure 4 some different ways of tags position relative to belt are shown.

Fig. 4. Possible tubular (A) tags vertical position relative to belt: across, skew, along (left to right, respectively)

Also location of the reading antenna relative to the moving belt was investigated. For the equipment 1 alternative locations of the sensor (containing the reading antenna) are possible. Location under and next to top belt strand (Fig. 5) were selected for tests. For the equipment 2 the location of the reading antenna under the top belt strand is the only recommended and was used for tests (Fig. 6).

Parameters of the reading equipment were tuned to get the best reading signal and the reading data were interpreted with the use of dedicated PYTHON scripts. All these arrangements were treated as a preparation stage for the in-situ tests.

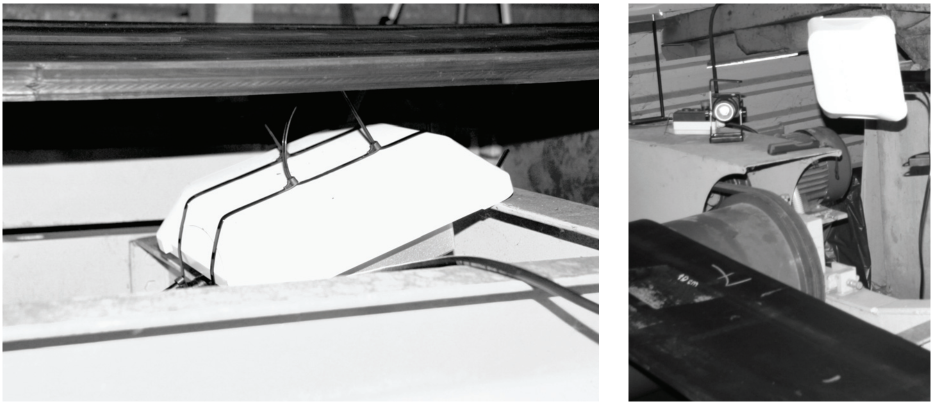

Fig. 5. Two alternative, tested positions of the equipment 1 sensor (white box) that detects RFID tags on the conveyor belt (black strand): under the top belt strand (left photo), next to the belt (right photo)

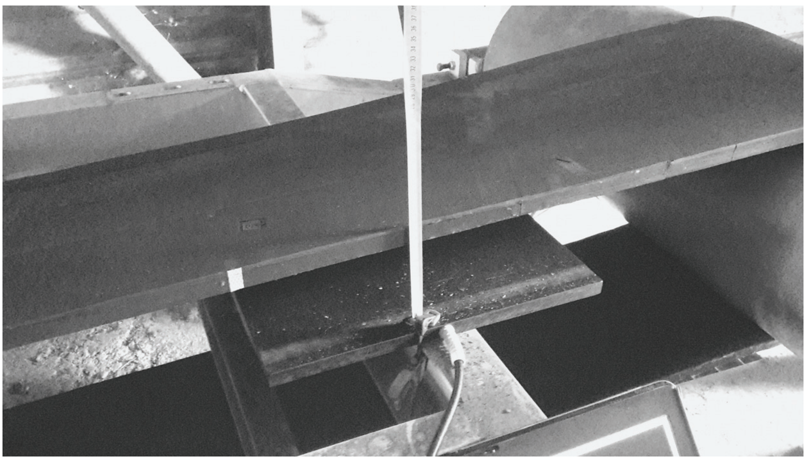

Fig. 6. The position of the equipment 2 reading antenna (black square table) – under the top belt strand

3.3. TEST RESULTS

Sensor from the equipment 1 can be put both: under and above the belt. That is why (to make comparison) tests were made for two variants of sensor location. In the case of this equipment no relation between position of tags and quality of measurements was observed.

For the sensor located under the belt measurements made with 0–0.10 m of the ore prism height were correct in 100% for 1 and for group of 3 tags. Also the belt speed did not influence the results. In the case of 0.20 m of the ore prism height variant measurements were correct for a single tag almost in 50%. In the variant with a group of 3 tags and the thick ore prism (0.2 m high) not all tags were read correctly (0, 1 and maximum 2 tags were read). For the group of 5 pellets and the thick ore prism maximum 3 tags were read, but sometimes none. In any variant relations between speed of belt and quality of measurements was observed.

For the sensor located above the belt measurements made for 1 tag were correct at any belt speed and at any ore layer height. For a group of 3 tags all measurements made with 0 and 0.10 m of the ore prism were correct. In the case of 0.20 m of the ore layer (no matter what the speed was) from 1 to 3 tags were read. It was similar with the group of 5 tags. In variants with 0 or 0.10 m of the ore prism all tags were read correctly but when ore prism reach 20 cm – from 1 to 5 tags.

According to the previous chapter, the sensor from the equipment 2 due to its construction cannot be located beneath the belt so for both types of tags measurement was made with the sensor installed under the belt (Fig. 6). During the tests some problems with reading even a single pellet appeared. That is why relations between position of tags (relative to belt which is equal with relative to sensor) and their readability were investigated. A type (small) tags located vertically or horizontally (along or skew) were read correctly. If the tags were located horizontally and across they were not recognised. B type (big) tags located vertically and across or horizontally and across were read correctly. If tags were put along or askew they were not read at all. These observations comply with the results of experiments presented in (Kvarnström & Vanhatalo 2010).

For a group of 5 A types tags, no matter what the speed was, maximum 2 tags were read. A single tag (irrelevant of the belt speed) was read beneath the ore prism not thicker than 0.10 m. When the ore prism was thicker none of tags was read. For a group of 5 tags even at the low speed (1 m/s) and not thick ore prism height (up to 0.1 m) only from 0 to 2 tags were read. The faster belt speed (maximum 5 m/s) decreased the quality of measurements. Similar relation was with the ore prism height covering tags.

Measurements for B type tags revealed that only with the low ore prism height (from 0 to 0.1 m) single tags were read. Speed of belts did not impact the result of measurements. For group of few pellets results were inaccurate even with low speed and no ore isolation. Not once all tags were read. With the increase of speed and level of the ore prism height quality of measurements got worse and for 0.20 m of ore – no tag was read.

For the most basic variant (1 tag, no ore and 1 m/s speed) each trial was successful. When the thickness of isolating layer of ore reached 0.1 m, only for tags A (equipment 2) percent of read tags decreased to 80. The variant with 0.2 m of the ore prism height appeared the worst and only equipment 1 with sensor above the belt gave positive results (Fig. 7).

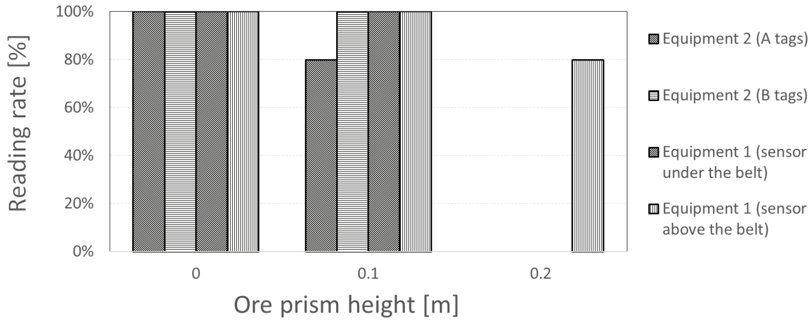

Fig. 7. Successfully read tags due to ore prism height (for 1 pellet in test and speed 1 m/s)

Measurements made with a single tag always gave positive results. If the number of tags increased for both A and B tags from the equipment 2 number of successfully read tags decreased. For groups of 3 or 5 tags it was always less than 50%. For the equipment 1, no matter how many tags were tested, always all tags were read (Fig. 8).

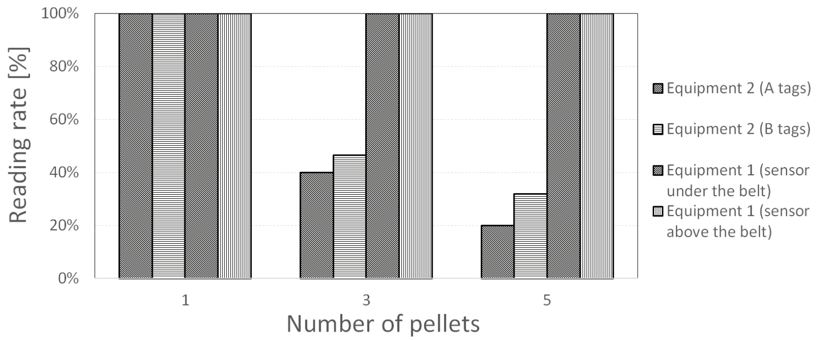

Fig. 8. Successfully read tags due to various number of pellets (for speed 1 m/s, without ore)

Speed of the belt had the lowest impact on the measurement result. All variants were fully successful, except A type tags from the equipment 2. In this case for the speed equal 3 or 5 m/s 80% tags were read correctly (Fig. 9).

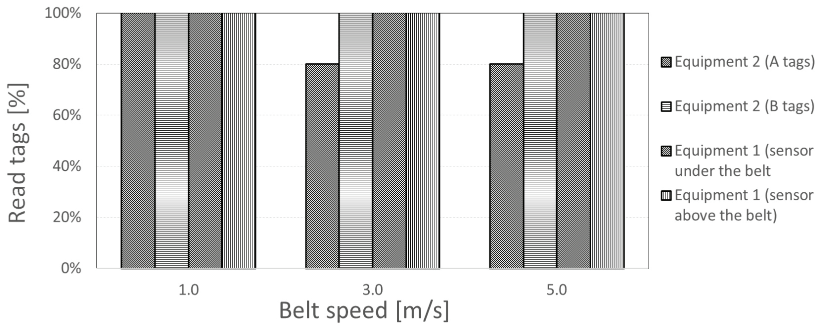

Fig. 9. Successfully read tags due to belt speed
(for 1 pellet in test and ore prism height equal 0.1 m)

4. CONCLUSIONS

The implementation of RFID tags for annotating transported material in the mining environment presents a number of challenges that were described in the literature. Tags can be damaged, lost or not read by sensors due to various reasons: unknown radio environment, adverse orientation relative to the reading antenna and mechanical or electrical interference. The investigation of RFID tags under these circumstances was done in the DISIRE project prior to the recommendation of their use for the mining applications (DISIRE report 2015).

Following the known experiments and the recognised mining environment of the Polish underground copper ore mines, the series of laboratory test were carried out.

The obtained and presented results of the tested two sets of measuring equipment provided the team with the important information about relations between different factors and the tags reading rate that was the measure of the quality of measurements. Not only the dedicated equipment (2) but also the standard one (1) proved to achieve the satisfactory reading rate of single tags. However the experiments confirmed that the reading equipment requires tuning to the environment interference that was described in (DISIRE Report 2015).

The important factor that could not be tested in the laboratory conditions was the impact resistance of tags conveyed among large ore lumps and subjected to entry crushing on the entrance to shaft skips. The survival rate of tags inserted into blast holes can be even as small as some 3% (Rabe et al. 2005).

The most important purpose of the laboratory experiments – the understanding of the factors that influence the readability of RFID tags (in fact – the traceability of ore annotated by tags) was reached and the gained knowledge was utilised during the preparations and proceeding of the industrial tests that eventually were successfully carried out in the underground copper ore mine Lubin in November 2017.

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