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Method for assessing belt tracking stability in man-riding belt conveyors

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Abstract:

This paper presents an original method for assessing the stability of belt tracking in conveyor belts used for personnel transport in underground mining conditions. The proposed approach is based on continuous measurement of the transverse inclination of the belt using a mobile diagnostic device equipped with an inertial measurement unit (IMU) moving together with the conveyor belt along its entire route. The method enables the spatial identification of local route deformations that may lead to noncentered belt tracking and negatively affect the safety and comfort of transported personnel. The effectiveness of the proposed diagnostic method was verified under real operating conditions in an underground coal mine. A series of repeated measurement runs was performed on the same conveyor route, allowing the repeatability and stability of the obtained results to be evaluated. The analysis was carried out by dividing the route into fixed-length sectors and calculating the maximum absolute transverse inclination values, as well as the coefficient of variation as a quantitative measure of the measurement repeatability. The results demonstrate high repeatability of measurements, with the coefficient of variation remaining below 0.6% along the entire conveyor route. The spatial distribution of transverse belt inclination confirms that the recorded deviations are mainly determined by the geometry and condition of the conveyor route rather than random measurement disturbances or belt-related effects. The proposed method provides a reliable and objective tool for assessing the stability of the belt tracking and identifying potentially hazardous sections of conveyor routes used for personnel transport. Its application may support preventive maintenance activities and contribute to improving the safety of crew transportation systems in underground mines.

Keywords: belt conveyor, personnel transport, man-riding conveyors, diagnostics, IMU, conveyor route geometry, safety

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1. Introduction

Transport in underground mining operations is one of the key elements of mine organization and has a direct impact on both the efficiency of work crews and the level of occupational safety. Depletion of mineral resources located in the immediate vicinity of the shaft infrastructure requires the exploitation of deposits situated at increasingly greater distances from the main transport systems. As a consequence, the mining faces are located progressively farther from the shafts, resulting in a significant extension of the access routes and an increased travel time for workers reaching their workplaces.

This phenomenon places growing demands on personnel transport systems. Traditional solutions based on floor-mounted railways and suspended rail systems increasingly prove to be insufficient in terms of routing flexibility and operational efficiency. In response to these limitations, alternative crew transport systems have been implemented in underground mines, most notably belt conveyors adapted for personnel transport [1]. Such solutions allow for a substantial reduction in crew travel time and a decrease in operating costs [2].

At the same time, the transport of personnel imposes requirements on belt conveyors that differ significantly from those associated with conventional bulk material handling, particularly with regard to belt tracking stability and the maintenance of proper conveyor route geometry. Existing technical supervision methods for belt conveyors, largely based on visual inspections performed by authorized inspectors, do not provide objective or quantifiable information concerning belt tracking behavior (Fig. 1).

a)  b) 

Fig. 1. View of the conveyor route used for personnel transport: (a) inspector's perspective, (b) transported person's perspective

In practice, the first indication of deteriorating operating conditions is often the subjective perception of the transported personnel. In view of the above, it became justified to undertake research aimed at developing a new diagnostic method, which constitutes the subject of this study.

2. Belt Tracking and Personnel Transport Safety

According to the guidelines of the State Mining Authority regarding the transport of personnel using belt conveyors adapted for this purpose, proper design, adjustment, and operation of such systems play a crucial role in improving occupational safety and reducing the risk of accidents associated with crew transportation in underground workings [3]. These regulations highlight the need to implement appropriate technical and organizational measures to ensure safe operation [4].

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Ensuring stable and centred belt tracking is a fundamental condition for the safe operation of belt conveyors used for personnel transport. Deviations of the belt axis from the conveyor route axis not only lead to increased wear of the belt edges and cooperating components but may also result in an incorrect belt support on idler sets. Normative requirements specifying permissible belt misalignment primarily refer to steady-state operation under geometrically stable route conditions [5].

In real underground mining conditions, particularly in longwall gate roadways, meeting these assumptions is significantly hindered by dynamic interactions between the conveyor structure and the surrounding rock mass. Deformation of the mine gallery, cracking, and progressive deformation of the roadway geometry directly affect the conveyor route, leading to tilting of idler sets and displacement of the route axis (Fig. 2).

Fig. 2. Operating conditions of a belt conveyor in a longwall gate roadway – visible floor cracking and floor heave

Rock mass deformations induce additional loads acting on the conveyor route, which in turn result in asymmetric loading of the belt edges [6]. As a consequence, local transverse belt inclinations may occur and persist over extended sections of the conveyor route. In the case of personnel transport, such phenomena are particularly undesirable, as even relatively small but permanent belt inclinations adversely affect ride comfort and subjective sense of safety experienced by the transported crew, as a consequence of route geometry deformation [7].

As a result, even conveyors that fully comply with technical requirements at the commissioning stage may, during operation, exhibit a tendency towards non-centered belt tracking. This observation clearly indicates the need for diagnostic methods that allow objective assessment of belt tracking under actual operating conditions.

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3. Diagnostic Methods and Operational Limitations

Increasing requirements for the safety and reliability of belt conveyor operation in recent years have contributed to the intensive development of diagnostic methods. This issue is of significant operational importance, as noncentered belt tracking may result from conveyor route deformations, improper adjustment of guiding components, or their progressive wear. A major limitation of most available solutions is their stationary nature and focus on selected points along the conveyor route, which prevents the assessment of belt tracking geometry as a function of distance.

These systems are primarily designed for bulk material transport and do not take into account the specific characteristics of personnel transport, where even minor route deformations may have a significant impact on the safety of the transported crew. The literature reports numerous diagnostic methods for belt conveyors, including stationary solutions based on vibration analysis, acoustic signal processing, and geometric measurements; however, most of these approaches focus on material transport and exhibit substantial limitations when applied to assessing belt tracking stability during personnel transport in underground conditions [8–10].

The literature also indicates the potential use of inertial measurement units (IMUs) as components of systems to detect faults and operational irregularities on belt conveyors [11]. An analysis of the state of the art reveals a lack of mobile diagnostic systems capable of measuring belt tracking parameters during an actual run along the conveyor route. The dominant research trend involves vision-based methods employing machine learning algorithms [12]. Increasing attention is also paid to digital twin concepts for belt conveyors, in which real measurement data are compared with a virtual reference model to identify operational anomalies [13].

Despite the high effectiveness of the proposed solutions, their application in underground mining conditions encounters significant limitations. Vision-based systems require permanent camera infrastructure, adequate lighting conditions, and an unobstructed field of view, which are difficult to ensure in underground mines [14, 15]. Moreover, these methods do not directly capture dynamic phenomena associated with belt motion, such as vibrations or accelerations. For this reason, it is justified to look for alternative diagnostic approaches that allow the assessment of belt tracking directly during belt movement and under real operating conditions of the conveyor.

4. Concept of the Proposed Diagnostic Method

In the context of personnel transport safety, even relatively small belt inclinations persisting over extended sections of the conveyor route should be regarded as a risk factor. Their early detection enables the identification of potentially hazardous locations and the implementation of corrective actions before unsafe operating conditions of the conveyor occur.

The diagnostic method is based on the analysis of the geometric configuration of the belt during its actual movement along the conveyor route. Under proper operating conditions, the belt is tracked centrally, and its left (A) and right (B) edges lie in a common transverse plane perpendicular (1) to the axis of the conveyor route (Fig. 3). Under such conditions, the loads transmitted through the idler sets are distributed symmetrically, which contributes to stable belt motion and limits lateral interactions.

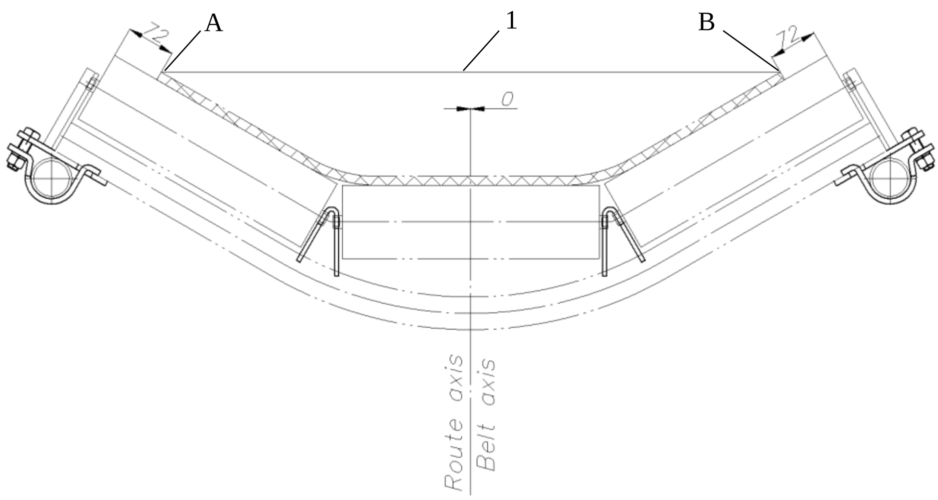

Fig. 3. Correct belt tracking in the upper idler sets of the conveyor route

In the presence of deformations of the conveyor route structure, uneven settlement of the roof and floor, or improper adjustment of the idler sets, the belt may lose its symmetrical position with respect to the conveyor route axis, resulting in lateral displacement. This leads to an inclination of the transverse plane of the belt (item 1), caused by the height difference between the left (item A) and right (item B) edges of the belt. This phenomenon can be described by the transverse inclination angle of the belt (Fig. 4).

Figure 4 illustrates the limiting position of the conveyor belt within the upper idler sets of the route at which full belt support by the idler set is still maintained. The illustrated condition corresponds to a situation in which the line connecting the two edges of the belt is inclined by 4.5°. This case represents a limiting operational state; beyond this value, partial loss of belt support may occur, leading to deterioration of safe conveyor operating conditions. In the remainder of the article, asymmetric belt inclination will be identified using the inclination angle defined above.

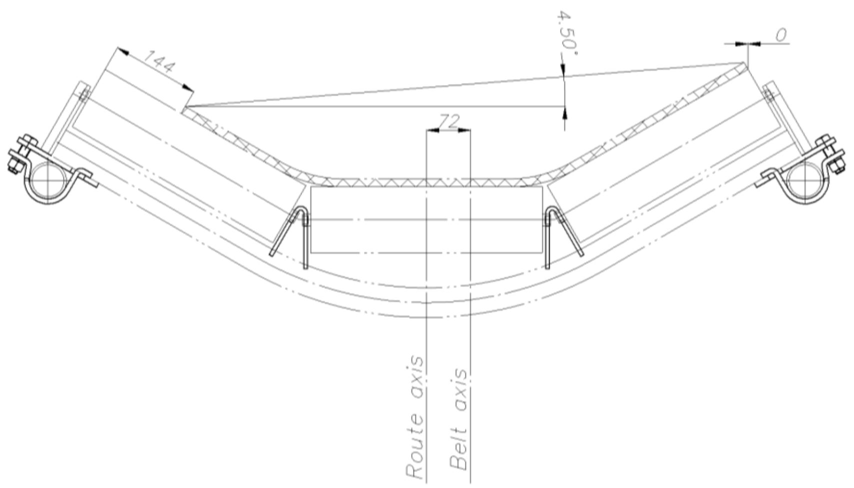

Fig. 4. Limiting threshold of belt tracking in the upper idler sets of the conveyor route

In the proposed diagnostic method, an asymmetric belt inclination is measured using an inertial measurement unit (IMU) located in the central part of the diagnostic device. Data acquisition is performed during a diagnostic run along the entire conveyor route. The recorded signals are subsequently filtered to reduce noise components and transformed into a distance-based representation, which enables the unambiguous assignment of inclination angle values to specific spatial locations along the conveyor route.

5. Mobile Diagnostic Device

The construction and functional assumptions of the author's diagnostic system designed to assess belt tracking in a belt conveyor are presented below. Figure 5 shows a general view of the device, illustrating the arrangement of the arm central module and the system mounted on the edges of the belt edges, which allows the device to adapt to the variable geometry of the conveyor route.

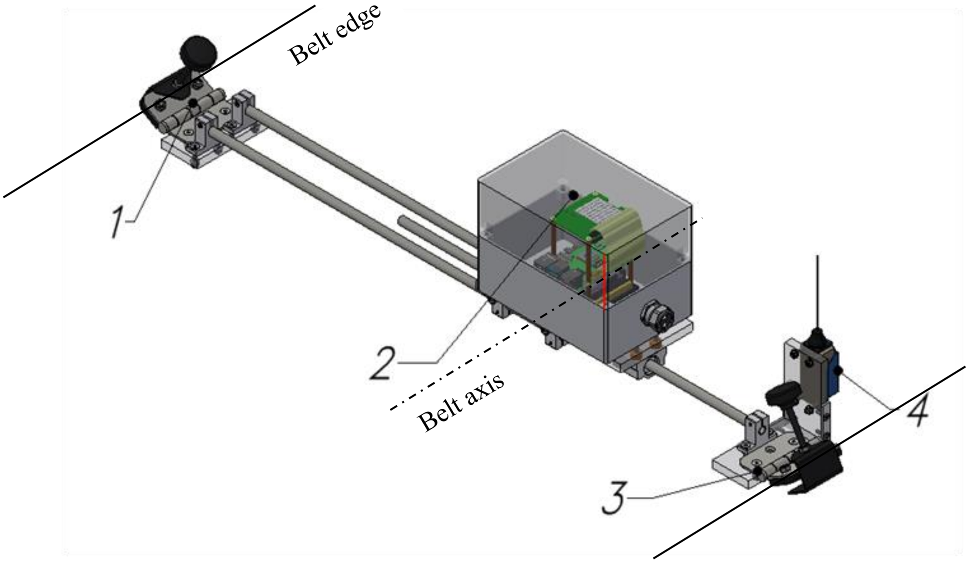

Fig. 5. Isometric view of the proposed diagnostic device
(1 – left clamp, 2 – central module, 3 – right clamp, 4 – mechanical limit switch)

The central module containing the measurement electronics is housed in an enclosure that provides protection against dust, moisture, and mechanical damage, ensuring reliable operation under mining conditions. Additionally, a mechanical limit switch type ME-8169, equipped with a spring-loaded lever, is installed in the right mounting arm of the system [16]. This component is used for precise detection of the moment when the device comes into contact with the measurement gate, indicating the beginning and end of passage through the reference point along the conveyor route. The limit switch enclosure has an IP65 protection rating, which guarantees proper operation even under conditions of high dust concentration and increased humidity. The limit switch is utilized in data synchronization algorithms, enabling automatic extraction of complete measurement records corresponding to individual runs of the device along the conveyor route.

The system interface is based on a Raspberry Pi 5 single-board computer, which enables the use of the native PCIe 2.0 interface for data storage. Instead of standard data recording on microSD cards or USB storage devices, a Raspberry Pi M.2 HAT+ module was used, allowing a high-speed NVMe solid-state drive to be connected directly to the PCIe bus [17-19]. This solution provides actual write speeds of approximately 500 MB/s, representing a significant improvement in both performance and durability of measurement data storage compared to conventional microSD media. The IMU sensor communicates with the central unit via a USB interface, ensuring stable data acquisition.

Figure 6 presents the complete, ready-to-use mobile measurement system installed directly on the belt conveyor route. The system consists of a measurement device (1) equipped with an IMU sensor that moves along the conveyor belt (4) and records acceleration and orientation parameters while travelling along the conveyor route (3). The measurement gate (2) acts as a reference point that triggers and synchronizes the measurement, enabling precise identification of the start or control point of the measurement run.

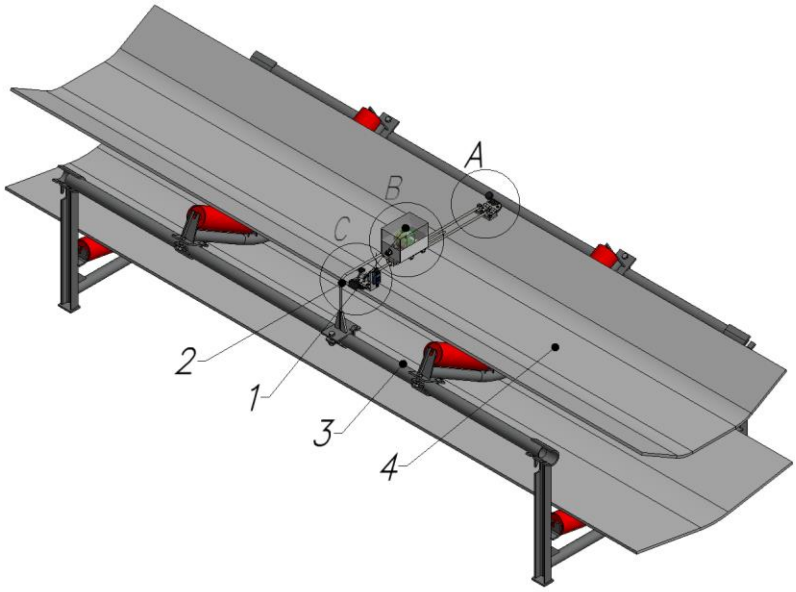

Fig. 6. Structural diagram of the measurement system with an IMU sensor (1 – measurement device, 2 – measurement gate, 3 – conveyor route, 4 – conveyor belt)

The entire structure was mounted on the conveyor route in a way that ensured mechanical stability and continuous contact of all components with the belt during its motion. The proposed solution enables measurements to be carried out under real operating conditions without any interference with the conveyor structure. Figure 7 shows the complete, ready-to-use mobile measurement system installed directly on the belt conveyor route.

Fig. 7. Diagnostic device installed on the belt conveyor route

The design of the author's device enables repeatable measurements of belt tracking parameters under underground mining operating conditions, while ensuring high reliability of data acquisition. The applied hardware solutions allow precise synchronization of measurements and their unambiguous reference to the position of the device along the conveyor route.

6. Validation of the Measurement Method under Operating Conditions

The evaluation of the effectiveness of a diagnostic method requires an analysis of the repeatability of results obtained in successive measurement cycles. Of key importance in this regard is the ability to compare current results with a reference baseline and to identify possible changes in belt behavior over time. For this purpose, the measurement method validation process was carried out on the same section of the belt conveyor, between belt splices, while maintaining a constant location of the diagnostic device. In each case, the device was installed at the same reference point on the conveyor belt.

As part of the experiment, eleven measurement runs were performed along a conveyor route section with a total length of 2340 m. The first run was adopted as the baseline run, while the remaining ten runs were used for comparative analysis. To standardise the evaluation, the route was divided into 100-m-long segments. Within each segment, the maximum absolute values of the transverse belt inclination were determined, as well as the differences of these values relative to the baseline run. In addition, the proportion of the route length for which the inclination angle exceeded the threshold value of 4.5° was calculated.

The indicators defined in this way enable a quantitative assessment of measurement repeatability and belt behavior stability in successive measurement cycles. Figure 8 presents the repeatability distribution of the measurement along the conveyor route, expressed by the coefficient of variation (CV) calculated separately for consecutive 100 m sectors. The coefficient of variation (CV) is a dimensionless measure of relative variability, defined as the ratio of the standard deviation to the mean value of the analyzed quantity, expressed as a percentage [20]. It allows comparison of measurement dispersion independently of absolute values and is commonly used to assess the repeatability and stability of measurement processes.

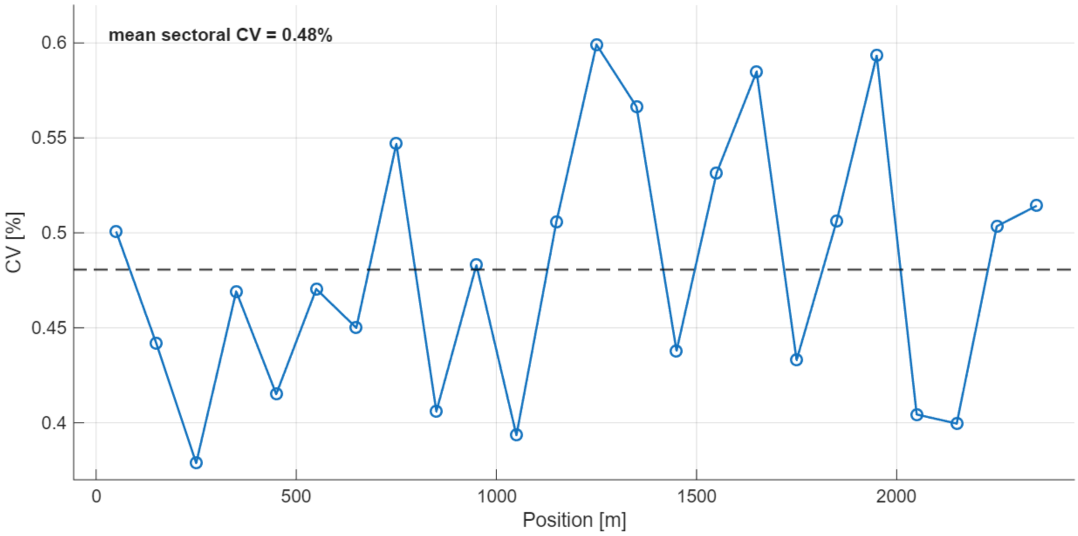

Fig. 8. Distribution of the coefficient of variation (CV) of transverse belt inclination measurements across route sectors

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CV values remain within the range of 0.38 to 0.60 %, while the mean sectoral CV is equal to 0.48% (dashed line), indicating high stability of the measurement results throughout the entire analysed route length. Minor local increases in CV observed in sections between approximately 1200–1400m and 1600–2000 m do not alter the overall picture of repeatability of the measurement and may result from temporary changes in belt loading, vibrations of the supporting structure, or local irregularities in belt support.

The obtained coefficient of variation profile confirms that the recorded transverse belt inclination is predominantly determined by the geometry and condition of the conveyor route, whereas variability associated with successive operating cycles does not significantly affect the measurement results.

7. Conclusions

The method proposed by the author to assess the stability of the belt tracking enables a quantitative evaluation of the inclination of the transverse belt as a function of distance and an unambiguous identification of sections of the conveyor route sections characterised by an increased operational risk. In situ validation tests confirmed the effectiveness of the system and its resistance to typical underground mine environmental conditions. The results obtained indicate the capability for early identification of conveyor route irregularities and belt tracking asymmetry.

The developed system constitutes a practical engineering tool that supports the assessment of personnel transport safety using belt conveyors and can be applied both for routine monitoring of the technical condition of the conveyor route and for verification of the effectiveness of corrective measures. Validation of measurement data obtained during successive runs, performed for the same reference point located on the conveyor belt, demonstrated very high repeatability of the results, expressed by a coefficient of variation of CV = 0.45%. The results also confirmed that the recorded transverse belt inclinations are determined by the geometry of the conveyor route rather than by the local properties of the belt loop.

The findings obtained confirm the validity of applying the proposed method as a reliable diagnostic tool for assessing the stability of belt tracking under operating conditions.

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