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Failure analysis of conveyor belt in terms of impact loading by means of the damping coefficient

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ABSTRACT

Detailed examination of conveyor belts in practice indicates a strong impact of the wear and damage, caused by the dynamic impact loading, on the conveyor belt service life. To examine the effects of the impact process, the theoretical, experimental, and numerical analyses were carried out, including the determination of the degree of damage to conveyor belt cover layers and chassis. The impact process analysis is based on the hypothesis that the movement of an object falling onto the conveyor belt and then bouncing on it is similar to the damped harmonic motion. The hypothesis is confirmed by the verification study of model (calculated) damping coefficient values, whereas the damping coefficient values were obtained from the experiment at various values of input parameters for the impact process, such as the drop height, weight of the falling object, and presence or absence of idlers.

The numerical modelling of the impact process was carried out applying the basis statistical methods and the multiple regression analysis. The output thereof represents the created regression models of the damping coefficient. The results of the process of conveyor belt wear and damage, in terms of dynamic impact loading, provide a new approach to the determination of the conveyor belt impact resistance based on the damping coefficient.

1. Introduction

The task of transportation within the conveyor belt systems can be defined as a process aimed at the transportation of the determined quantity of handled material within a defined period of time between the specified loading and unloading locations [1]. As the belt speed adjustment alters the material discharge parabola at the discharge points, discharge chutes capable of such load are required to avoid severe wear of the chute and the receiving belt conveyor [2]. The economic significance of the costs caused by the wear is enormous. The handling of bulk solids is generally associated with significant wear to the plant equipment and the components used [3]. To ensure operational reliability of the conveyor system consisting of belt lines, proper design of chutes, in terms of kinematic, dynamic, and energetic conditions is a very challenging task [4]. During the conveyor belt operation on a belt conveyor, the belt is gradually worn out and damaged as a result of deterministic and stochastic stresses that do not affect it concurrently, but in certain time intervals. Risk factors include the multiaxial impact compressive stress, shear stress, and stress in the bending, induced by impact forces at transfer chutes, which cause the wear of the cover layers and often even punctures of the entire conveyor belt. Transfer chutes are critical areas within the conveyor systems, in terms of maintenance and high levels of energy consumption. A conventional transfer chute design is relatively simple. Fundamentally, standard steel section and plates

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are used with additional removable linings made of other materials which act as the protection against wear. The method of conveyor belt wear depends on a large number of factors [5]. One of the main reasons of the conveyor belt wear is the stress caused by the impact of lumpy material [6]. Reicks et al. [7] applied various theoretical and experimental methods in the research of the most important aspects of the belt conveyance. Methodology for the testing of conveyor belts, particularly their service life affected by the cover layers wear, is discussed in papers [8–10].

Another important factor of the conveyor belt wear is a proper choice of the support system. Authors Gondek, Neruda, Pokorny [11] extensively discussed the rock impact dynamics, a new type of device - the impact rods intended for significant reduction of the number of punctures in conveyor belts and thus for the prolongation of their service life and modelling of the proposed devices.

Analysis of the conveyor belt wear, in terms of impact loading during the interaction between the support system and the conveyor belt, has been described by many authors in experimental papers [9,12], but it has never been transformed into a standard. One of the first papers dealing with the experimental research of the conveyor belt resistance to impact loading is the paper by Köttegen [13] in which the author conducted the registration (of the record) of impact force pulses and documented that belts supported by another belt at the impact (filling) point have stronger ability to absorb the impact energy, compared to belts supported by idlers. Another author, Vierling [14], provided a detailed analysis of the impact of various conveyor belt structures on the impact loading at feed points. According to Vierling, critical energy, as defined therein, should be a conveyor belt characterizing parameter, depending only on structural parameters and physical-mechanical properties of a conveyor belt. This hypothesis has not been confirmed by subsequent research carried out by authors Flebbe, Hardygora [15] and Hardygora, Golosinska [16] which proves that the value of critical energy depends on the method of belt support and the shape of the falling object's edge. All experimental measurements and research carried out by the above mentioned authors were focused primarily on the identification of dynamic effects and reactions in the conveyor belt - idlers system and were based on certain general rules that designate the effect of the material's fall onto a belt as the impact energy. For the purpose of better understanding of the loading process, with regard to these effects, Ballhaus [17] determined the impact forces of an object free falling onto the conveyor belt. The loading point impact is one of the main causes of the conveyor belt wear. Complex results of this research were carried out for the purpose of accurate determination of the effects: belt speed, drop height, initial strain and thickness of damping layers made from various materials.

Theoretical, experimental and numerical analyses of conveyor belt service life, from the impact point of view, were also carried out by authors Bocko et al. [18]. Their main objective is to increase the service life of a conveyor belt by optimisation of sizes and shapes of transported parts, the drop height, the belt design, and the impact area. The latest results of the impact resistance are presented in papers [19–23].

With regard to the support system and the conveyor belt properties, the study by authors Kinoshita, Okubo, Fujii [24] states that the resistance force of the carrier roller increases with an increase of the roller speed and decreases when the lower damping rubber is used, whereas the belt rigidity does not affect the resistance force, if low resistance rubber is used. Similar experimental research was carried out also by authors Bajda, Hardygora, Gladysiewicz [25] who state that the theoretical analysis, as well as experimental tests, showed the possibilities of reducing the belt rolling resistance through the change of elastic properties and damping of the belt cover.

A new high-speed impact cradle, which has solved the problems with roller and frame damage from heavy conveyor loading conditions, is described by Felde [26]. These new cradles were designed using the finite element analysis, so we could confirm that they would be strong enough, without having overbuilt them. The innovative load zone design uses an elastomer bar suspension system that absorbs and distributes the material load being transferred, greatly reducing the stress on the idler rolling components and the support structure.

2. Material and methods

2.1. Problem formulation

The moment at which the material with certain weight and speed contacts a conveyor belt is followed by the elastoplastic impact. The value characterizing the impact course is the impact force pulse, whereas its intensity and direction depends on many factors, such as drop height, transported material characteristics, conveyor belt type, and support system structure.

Description of the conveyor belt wear process is complex and requires addition or acquisition of relevant results. Execution of the operational research is time-consuming and costly. Laboratory research is more appropriate in order to obtain objective results. The article presents the results of the laboratory research focused on the conveyor belt wear with the purpose to determine the interaction between the impact of an object represented by the falling object's weight, the drop height, and the support system at the transfer point. To describe the impact process, the applied approach uses the theory of damped harmonic motion through the damping coefficient determination.

2.2. Realisation of experiment

The experiment was realised by means of the testing equipment, which is illustrated in Fig. 1. The testing equipment includes the hydraulic system for the attachment of a belt sample (Figs. 1, 2), another hydraulic system for stretching the sample during the test, and a laser scan recording the actual height of a drop hammer in time. The structure of the testing equipment is based on