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Theoretical and experimental determination of the pressure distribution on a loaded conveyor belt

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ABSTRACT

The objective of this study is to determine the pressure distribution caused by bulk material on a loaded conveyor belt using theoretical and experimental approaches. The determination of the pressure distribution is important for the engineering design of conveyor belts and the analysis of the belt–bulk material interaction. A theoretical model has been developed to predict the pressure distribution but not fully verified yet. There has been no satisfactory method for the direct measurement of the pressure. Using a tactile pressure sensor, we measured the pressure distribution directly on a running conveyor belt. The measured pressure is assessed using a conveyor scale. High pressure regions are identified. Comparisons between theoretical and experimental results indicate that a good correlation has been achieved and the theoretical model is further verified. The study attests the applicability of both theoretical and experimental approaches for the determination of the pressure distribution on loaded conveyor belts.

1. Introduction

Belt conveyor systems are widely utilized in continuous transportation of large volumes of bulk materials for long distances. The conveyor belt, which spans between the drive and return pulley, conveys bulk material along its movement over numerous idlers. The primary mechanical function of the belt is to bear the transported bulk material during conveyance. Consequently, the pressure distribution caused by the bulk material on the belt is important information for the engineering design of the belt [1,2]. The pressure distribution can also enhance further research on the belt–bulk material interactions, for example the bulk flexure resistance [3].

The theoretical analysis of the pressure distribution caused by the bulk material on a loaded conveyor belt is complicated due to cyclic active and passive stress states in the bulk material [4]. Several researchers have contributed to the theoretical calculation of the pressure distribution on the belt. Based on Coulomb earth pressure theory, Krause and Hettler [5] first developed an analytical model (KH model) to calculate the forces on the Wing Belt Sections (WBSs in Fig. 1) and the Centre Belt Section (CBS). The KH model is widely accepted though it is realized that the KH model overestimates the forces on the WBSs compared to experimental results [6]. Recently, the authors have developed another analytical model (SD model) to calculate the pressure distribution based on the stress discontinuity method [7]. The SD model incorporates a new hypothesis of bulk movement on the belt and rigorous stress field analysis. A good correlation has been achieved between the two models. Though the SD model has been verified by the measurements of the forces on idler rolls in an indirect approach, further verification necessitates comparisons with direct measurement of the pressure on the conveyor belt.

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Nomenclature

f_d	dynamic factor (–)
g	acceleration of gravity (m/s^2)
x	distance along the wing belt section (m)
z	depth of bulk material element from surface (m)
L_1	length of bulk material along the wing belt section (m)
K_a, K_p	coefficients in active and passive stress states (–)
R_1, R_2	radiuses of Mohr circles (N/m^2)
α	trough angle of the idler configuration (–)
β	conveyor surcharge angle of bulk material (–)
δ	strength mobilized on the stress discontinuity (–)
θ_a, θ_p	rotations of the major principal stresses in active and passive stress states (–)
ρ	density of bulk material (kg/m^3)
$\sigma_{OC1}, \sigma_{OC2}$	average effective stresses in active stress state (N/m^2)
$\sigma_{w,a}, \sigma_{w,p}$	normal stresses in active and passive stress states in zone 2 (N/m^2)
$\tau_{w,a}, \tau_{w,p}$	shear stresses in active and passive stress states in zone 2 (N/m^2)
φ_i	internal friction angle of bulk material (–)
φ_w	wall friction angle between the belt and bulk material (–)
$\Delta_1, \Delta_2, \Delta_3, \Delta_4$	angles in Mohr circle (–)

On the other hand, direct measurement of the pressure caused by the bulk material on a running conveyor belt remains a challenge. Literature showed that there has been no satisfactory sensors or procedures for the direct measurement of the pressure. Previous experimental studies focused on measurements of the forces on idler rolls using load cells or strain gauges (e.g. [8–10]). The measured forces on idler rolls provide indirect estimation of the pressure distribution on a loaded conveyor belt. However, these apparatuses only provide a few measuring points which limits the information of the pressure distribution.

Recent development in the tactile sensing technology provides an opportunity to measure the pressure distribution on a loaded conveyor belt directly. Tactile pressure sensors have been proven to produce acceptable measurements of the pressure in both static and dynamic environment for scientific purposes, e.g. the normal stress distribution in a Jenike shear cell [11], the normal wall stresses in hoppers [12], loads on the support structures buried in bulk stockpiles [13], the pressure within the rail/tie interface [14].

Meanwhile, the tactile pressure sensors have intrinsic limitations. The accuracy of measurements largely relies on a customized calibration process. However, it is quite a challenge to simulate the flexible curved contact between the sensor pad and the loaded belt during calibration. Furthermore, the sensors can also be influenced by the loading rate, the hysteresis and creep [15]. Further

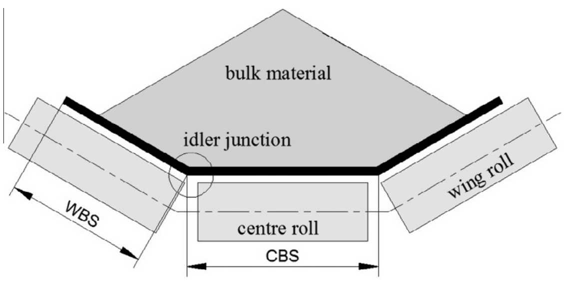

Fig. 1. Schematic cross-section of a loaded conveyor belt. The conveyor belt is artificially divided into two Wing Belt Sections (WBSs) and one Centre Belt Section (CBS).

limitations like inaccuracies between individual sensels were also reported [16]. As a result, special attention should be paid to the experimental setup and procedures to minimize the intrinsic limitations of the tactile pressure sensors. Ilic carried out a pilot study on the measurements of the pressure on a loaded conveyor belt using a tactile pressure sensor [6]. But the accuracies of the measurements were not assessed.

The objective of this study is to verify the SD model and to assess the applicability of the tactile pressure sensors for the direct measurement of the pressure on a loaded conveyor belt. The pressure is theoretically calculated using an analytical model. Experimental study is carried out on a running conveyor belt with varied loading levels. The direct measurement of the pressure distribution on the loaded belt is achieved using a tactile pressure sensor. The measured pressure is assessed by comparisons with measurements from a conveyor scale. The assessment proves the efficacy of tactile pressure sensors for the measurement of the pressure on conveyor belts. Results from both the theoretical model and the tactile pressure sensor are analyzed and compared according to different loading levels. Comparisons indicate that a good correlation has been achieved and the theoretical model is further verified. The study attests the applicability of both theoretical and experimental approaches for the determination of the pressure distribution on loaded conveyor belts.

The outline of the paper is as follows. First, the theoretical determination of the pressure distribution is formulated. Then the experimental setup as well as execution procedures are introduced. In results and discussion section, we assess the acquired data, present the measured pressure, and compare the pressure distribution from the theoretical model and measurements. Some conclusions are drawn in the last section.

2. Theory/calculation

The theoretical calculation in this section is based on the SD model developed in a previous study elaborated in Ref. [7]. By incorporating a new hypothesis of the