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Green operations of belt conveyors by means of speed control

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HIGHLIGHTS

- Speed control of a long inclined belt conveyor is implemented.
- Daily energy reduction of about 12.2% is enabled due to speed control.
- Yearly energy saving of about 160 MW h is shown.
- €11,000 electricity cost and 90 tons CO_2 emission are reduced annually.
- ECO method ensures safety operations of speed control.

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ABSTRACT

Belt conveyors can be partially loaded due to the variation of bulk material flow loaded onto the conveyor. Speed control attempts to reduce the belt conveyor energy consumption and to enable the green operations of belt conveyors. Current research of speed control rarely takes the conveyor dynamics into account so that speed control lacks applicability. Based on our previous research, this paper will provide an improved three-step method to determine the minimum speed adjustment time. This method can be summarized as Estimation-Calculation-Optimization and ECO in short. The ECO method takes both the potential risks and the conveyor dynamics into account. It is expected to keep belt conveyors in good dynamic behaviors in transient operations. After discussing the ECO method, this research takes a long inclined belt conveyor of an import dry bulk terminal as case study. Based on the suggested acceleration time, a speed controller is built and computational simulations are carried out to evaluate the energy savings and the conveyor dynamics. Experimental results prove that the application of the ECO method ensures the healthy dynamic performance of belt conveyors under speed control in transient operations. Annually, the average electricity consumption of the single conveyor can be reduced by over 10% with around 90 tons reduction of CO_2 emission. The direct economic benefit can reach up to more than €10,000 in terms of the electricity utilization per year.

1. Introduction

Belt conveyors play a significant role in the dry bulk handling systems. Due to the development of rubber technology, conveyor belts improved significantly after the Second World War and the application of belt conveyor systems for the transportation of bulk materials became widespread [1]. There are more than 2.5 million conveyors in operation annually in the world [2]. Considering the extensive use of belt conveyors, the operations of belt conveyors require a large amount of electricity. Taking the challenges associated with the environmental pollution and the electricity availability in some parts of the world into account [3–5], there is a strong demand for lowering the energy consumption of belt conveyors to reduce the operational cost and the carbon footprint. In the past decades, belt conveyor speed control has been proven to be an important method for realizing the green operations of belt conveyors.

Belt conveyor speed control is defined as a method of adjusting the conveyor speed to reduce energy consumption [6]. Generally, belt conveyors are running at designed nominal speed and in the most cases the belt conveyors are partially loaded. In such cases, the conveyor speed can be adjusted to match the material flow and the conveyor's filling ratio is expected to be significantly improved. Consequently, the belt conveyor's energy savings can be achieved. This is the so-called speed control. Besides the promising energy savings, extra benefits are also expected to be achieved by the applications of speed control, such as less carbon footprint and less mechanical and electrical maintenance [7–9].

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Speed control is not a new research concept and right now many researchers and engineers are studying the speed control of belt conveyors. However, these research mainly focus on the realization of soft start-up or stop operations [10–13]. The research of speed control for the purpose of reducing the power consumption of belt conveyors can be dated back to the end of last century [7]. In past few years, several important results have been achieved with respect to energy savings. Based on the standard DIN22101 [14], Hiltermann [8] proposed a methodology of calculating the energy savings via speed control. To verify the methodology the speed of a studied belt conveyor was adjusted during field tests by varying the output frequency of the installed frequency converter. According to the measurement of the studied belt conveyor, the speed control resulted in a 21% reduction of the total power consumption at certain operation conditions. Zhang [15] put forward a modified energy calculation model which combined energy calculations in DIN 22101 [14] and ISO 5048 [16]. Based on this model, the time-of-use tariff was considered in the relative research [17–19] and a model-predictive-control method was proposed to optimize the operating efficiency of belt conveyors. As the simulation result showed, both the electrical energy and the payment were considerably reduced by the variable-speed-drive-based optimal control strategy. Pang [20] proposed a fuzzy control method to adjust the conveyor speed in a discrete manner to avoid the risk of high belt tension in speed control. The experimental result showed that the fuzzy control system could be effectively applied to improve the energy efficiency of bulk material conveying systems. Further, a fuzzy logic controller was built by Ristic [21] for the purpose of applying speed control on belt conveyors. Measurements were carried out in a long period of time on a system composed of three belt conveyors with a total installed power of 20 MW. The data of the power consumption collected over eight months affirmed that the control strategy with fuzzy-logic-controller enabled the energy savings of belt conveyors.

However, it is important to note that the current researches of speed control rarely take the conveyor dynamics in transient operations into account. According to He [22], transient operations are operations in which the conveyor speed changes over time for the purpose of matching the variable material feeding rate onto the belt. Compared to those operations in normal start-up or stop activities, the transient operations for speed control should be given more attention since the belt conveyor is loaded with a high filling ratio during the speed control. Moreover, the dynamics of belt conveyors in transient operations is more complex, especially in cases where the conveyor speed is frequently adjusted to match a variable material feeding flow. Pang and Lodewijks [20] stated that in transient operations, a large ramp rate of the conveyor speed may result in very high tension on the belt, which is the major reason of belt breaking at the splicing area. Such risk of high belt tension must be prevented during speed control. Besides the risk of belt tension, the improper transient operations may also result in for instance the risk of belt slippage around the drive pulley and the risk of material spillage away from the belt. However, there are rare research outputs in literature showing the solutions or methodologies to prevent these risks in the transient operations for speed control, which lead to the lacks of belt conveyor speed control practice.

This paper is one step further of our previous work [22]. In our previous work, a three-step method was proposed to determine the minimum acceleration time, with which the transient operations successfully prevented for instance the risk of belt over-tension and the risk of belt slippage around the drive pulley. It was the first research output of improving the applicability of speed control. In this research, the previous three-step method is improved and summarized as Estimation-Calculation-Optimiza tion and ECO for short. An estimator firstly is built to estimate the demanded minimum acceleration time. Then the calculations are carried out to analyze the conveyor dynamic performance. If the risk of for instance belt slippage around the drive pulley occurs, optimizations are required to improve the conveyor dynamics until the required minimum acceleration time is obtained. This is the ECO method. The ECO method has the advantages of for instance preventing risks in transient operations and ensuring high dynamic performance of belt conveyors.

The objective of this paper is to show how to achieve green operations of belt conveyors by means of speed control. A long inclined belt conveyor of an import dry bulk terminal is selected to show the green operation via speed control. The studied belt conveyor is part of the bulk material handling chain in an import dry bulk terminal, where the material feeding flow to the belt is varying with the variable-in-time number of operating ship unloaders (e.g. rail-mounted grab cranes). The peak of the material flow feeding rate can be predicted according to the actual number of operating unloaders. Based on the principle of speed control, the conveyor speed is adjusted to match the actual material feeding flow to maximize the filling rate on the belt so that energy savings can be achieved. This research considers not only the magnitude of power savings of belt conveyors, but also the requirement of healthy dynamic performance. To realize the soft acceleration and deceleration during the speed control in transient operations, the ECO method firstly determines the minimum speed adjustment time for both acceleration and deceleration operations. With a suggested adjustment time, a speed controller is then built and a series of reference speeds are defined according to the variable-in-time number of operating ship unloaders. Finally, computational simulations are carried out to evaluate the speed control and to show the green operations of belt conveyors. The simulation outputs include the savings of the power consumption, of the electricity cost, of the CO_2 emission and of the operational cost.

In this paper, Section 2 illustrates the energy model of belt conveyors and the principle of energy savings by means of speed control. The detailed ECO method is introduced in Section 3 including the risks to be taken into account and the determination of speed adjustment time. In Section 4, based on the case study of a long inclined belt conveyor, the implementation of the ECO method is shown. Further, the green operation of belt conveyors is achieved in terms of the reductions of electricity and of CO_2 emission as well as of the total operational costs. Section 5 gives the conclusions and suggestions of the research.

2. Energy model and potential energy savings

2.1. Energy model

The energy model of belt conveyors is derived from the standard DIN 22101 [14] and the paper [8]. The driving force F_d exerted on the drive pulley equals the total motional resistances F_f adding the net forces F_A resulting in accelerating:

$$F_d = F_f + F_A \tag{1}$$

According to DIN 22101, the total motional resistances can be calculated by:

$$F_f = CfL\left[m'_{roll} + \left(2m'_{belt} + m'_{bulk}\right)\cos\delta\right]g + Hm'_{bulk}g + F_S \tag{2}$$

where C is a factor for calculating the secondary resistances, f stands for the artificial friction coefficient, L represents the conveyor length, $m'_{roll}, m'_{belt}, m'_{bulk}$ are idlers mass, conveyor belt mass and bulk material mass per length unit, respectively, δ represents the mean angle of inclination of the installation, H is the change in elevation between head and tail pulleys, g is the gravity acceleration and F_S