Powder Technology 301 (2016) 622–631

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Speed control of belt conveyors during transient operation

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ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 21 June 2016
Accepted 3 July 2016
Available online 5 July 2016

Keywords:
Belt conveyor
Speed control
Suitable acceleration
Optimal acceleration time
Risks

ABSTRACT

Belt conveyors play an important role in continuous dry bulk material transport. Large scale belt conveyor systems consume a considerable amount of electricity. The approach of controlling the belt speed in such a way that the belt's volumetric capacity is fully utilized under all operational conditions has been proven to significantly reduce the energy consumption of a belt conveyor. Current research on speed control for belt conveyors mainly focuses on the calculation and the prediction of possible energy savings. Few studies focus on the dynamics of belt conveyors in transient operation. There are however no studies that describe the operation of speed controlled belt conveyors during transient operation. This paper presents a three-step method that can be used to determine a proper way to accelerate a speed controlled belt conveyor during transient operation. This method takes the potential risks in transient operation and the conveyor dynamic performance into account. A case of horizontal conveyor system is studied and the three-step method is applied. In the case study, a predictor of the permitted maximum acceleration is calculated. Simulations with the predicted acceleration time are carried out to determine the acceleration operation and to analyse the conveyor dynamics. The simulations are based on an existing finite element model of a belt conveyor.

1. Introduction

Belt conveyors play a significant role in the continuous transport of dry bulk materials. After the Second World War, due to the significant improvements in rubber technology gained during the war, the applications of belt conveyors changed rapidly. Belt conveyors became longer, faster and more efficient with higher capacity and less environmental impact [1]. Considering their extensive use, the operations of belt conveyors involve a considerable amount of electric energy. For instance, in [2] an example is given showing that belt conveyors consume 50 to 70% of the total electric energy of a dry bulk terminal. Considering the challenges associated with the availability of power in some parts of the world and environmental pollution, there is a strong demand to reduce the power consumption of belt conveyors.

In the past decades, several energy saving solutions were proposed to reduce the energy consumption of belt conveyors [3,4]. The approach of speed control is an important one. In general, the belt conveyor is running at its nominal steady state speed and the average utilization of belt is less than the design capacity. This can be caused by temporarily or cyclic variations in the bulk material flow discharged on the conveyor or to allow for surge flows. The DIN standard (specially DIN 22101 [5]) suggests that considerable energy savings can be achieved by lowering the conveyor speed and improving the belt utilization. The method of adjusting the conveyor speed to adapt the material loading rate to full capacity is the so-called speed control [2]. Recent studies [2,6,7] prove the viability of speed control. If the belt speed is frequently adjusted to match the variable material feeding rate then this regulation is known as active speed control.

The solution of energy saving via speed control has already been studied for almost 20 years and a series of studies have already produced promising results. For instance, the methodology of calculating and predicting energy savings has been put forward by [8,9] and methods of optimizing the conveyor speed to achieve more energy savings has been put forward by [8,10–12]. However, the current research still faces two significant limitations.

Firstly, the conveyor's dynamic performance in transient operation has not been taken into account for setting up speed control algorithms. Although there are many papers analysing the conveyor's dynamic performance, they normally focus on the start-up from rest or the stop to rest operation. Here, differing from the normal start-up or stop operation, the transient operation is the operation regulating the belt speed to match the variable material feeding rate. That means that the initial belt speed and the belt speed after speed regulation is not zero. The transient operation includes the accelerating and decelerating processes. In this paper, the transient operation mainly refers to the acceleration operation.

Secondly, except for our previous research work in [13], there is a lack of studies describing methods to get the optimal speed regulation time in speed control. In a suitable transient operation, the belt conveyor has a good dynamic performance and risks like belt overloading or belt slippage are prevented. Pang [10] suggests that in transient

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http://dx.doi.org/10.1016/j.powtec.2016.07.004
0032-5910/

operation, the large acceleration may lead to damage of conveyor components or even total malfunctioning of the entire conveyor. So in transient operation, the acceleration time should be large enough to avoid the risks. On the other hand however, the acceleration time determines the feasibility of speed control, which determines the amount of energy savings that can be achieved via speed control. To improve the feasibility and achieve more energy savings, the acceleration time should be as short as possible. Therefore, getting optimal acceleration times in transient operation is essential to satisfy both the demand of preventing conveyor risks and the demand of maximizing energy savings. Taking the two demands into account, a three-step method is proposed to get the suitable acceleration operation with minimum acceleration time.

Before discussing the method to achieve a suitable acceleration operation, potential risks in transient operation are discussed. The risks mainly include the belt over-tensioning in the splicing area, slippage of the belt around the drive or brake pulley, motor overheat and material spillage. To prevent the mentioned risks, a three-step method is proposed to achieve a suitable transient operation with minimum acceleration time. This method takes both the potential risks and the conveyor dynamic performance into account.

Firstly, taking the potential risks into account, an initial estimator of the acceleration time is calculated yielding the maximum permitted acceleration and the initial acceleration time. This step is known as initiation, in which the belt tension rating, the conveyor tension ratio limitations around driven/braked pulleys, the motor torque rating and the acceleration profiles are taken into account. Secondly, conveyor dynamic analyses are carried out to calculate the belt tensions during the acceleration operation with initial acceleration time. The results of the conveyor dynamic analyses comes from simulations based on an existing finite element method (FEM) [14]. This step is known as calculation. Thirdly, in case of acceleration operation with risks, more simulations are carried out to improve the acceleration performance and to get the optimal acceleration time. This step is known as optimization.

To illustrate the three-step method more clearly, a horizontal belt conveyor is studied. The implementation of the case study will show the feasibility of the three-step method to achieve the suitable acceleration operation with optimal acceleration time. The main contribution of this paper is the presentation of a three-step method to achieve the suitable transient operation with optimal acceleration time. Besides that, this paper analyses the conveyor dynamic behaviour in transient operation with a finite element method. In addition, the potential risks in transient operation are discussed in detail. In this paper, Section 2 discusses the potential risks in transient operation. Section 3 describes the three-step method in detail. A horizontal belt conveyor system is studied in Section 4 in which the three-step method is implemented. The last section concludes the results and findings of this study.

2. Risks in transient operation

In cases of belt conveyors with variable material feeding rate, the conveyor speed needs to be frequently regulated to match the variable material loading rate in such a way that the conveyor's volumetric capacity is fully utilized. Pang [10] suggests that in transient operation, an unsuitable acceleration may result in the potential risks. These risks include:

i. *Belt over-tension*. The belt strength is mainly determined by the strength of its carcass. For a certain conveyor belt, the belt tension rating is a given and thus constant. In the acceleration operation, if the belt tension exceeds the permitted tension levels that are determined by the belt tension rating, the belt may break at a splice. Generally, the highest risk of belt over-tension in a horizontal conveyor occurs in the area right before the drive pulley. So in the acceleration operation, the belt tension before the drive pulley should be monitored, especially when the belt is fully loaded.

ii. *Belt slippage around the drive pulley*. Literature [15] states that if the drive torque exerted on the drive pulley is larger than permitted, the belt will slip around the drive pulley. Belt slippage may result in severe wear of belt bottom cover which causes the reduction of the belt's service life. In addition, if the belt slippage occurs to the extent that it slows down or even stops the conveyor then blockage of the belt's feeder chute or material spillage may occur.

iii. *Motor overheat*. The rated motor torque is the maximum continuous torque available at the design speed that allows the motor to do the work without overheating. In practical acceleration operations, the maximum service torque is allowed to be larger than the rated torque for a short time. The ratio between maximum service torque and rated torque is defined as service factor (SF). For example, the standard SF for open drip-proof motors is 1.15 [16]. In the acceleration operation, especially in active speed control, the motor service torque is not allowed to exceed the permitted. Otherwise, the motor may overheat.

iv. *Material spillage*. Due to the belt's elastic properties, the acceleration operation causes the fluctuations of belt tension and speed. If the amplitude of belt speed fluctuation is excessive, the belt nearby the loading area may be overloaded and bulk material may be spilt from the belt. Besides the fluctuation of belt speed, the large fluctuation of the belt tension may also lead to the material spillage caused by the sudden changes in belt sag. If the belt tension is excessively low and the belt drops significantly between the idlers then also spillage may occur. According to CEMA [17] bulk material may be spilled from belt when a conveyor belt sag ratio is >3%. During transient operation however, maximum belt sag of 3% may be acceptable depending on the utilization of the belt [14].

3. Method of achieving suitable acceleration operation with least acceleration time

In the research of belt conveyor dynamics, researchers are mainly focusing on the operation of a soft-start and/or a soft-stop. However, the conveyor dynamics in transient operation have not been taken into account for speed control and the acceleration time in transient operation also has not been discussed. On the one hand, large accelerations may result in non-acceptable conveyor dynamic performance. In transient operation, especially in active speed control, the four mentioned risks must be prevented. Accordingly, the acceleration time should be long enough to avoid the risks. However, on the other hand, the acceleration time determines the feasibility of speed control and influences the amount of energy savings. To improve the feasibility and to get more energy savings, the acceleration time should be limited. With respect to these two requirements for acceleration time, a three-step method is presented which is expected to achieve the suitable acceleration operation with minimum acceleration time. This method takes both the potential risks and the conveyor dynamics into account. Fig. 1 shows the flow diagram of the method. It is important to note that in the optimization part, increasing the acceleration time is only one of the potential solutions. For instance, altering the acceleration profile also can receive softer acceleration operation.

3.1. Initiation

With respect to the potential risk, the initiation takes the belt tension rating and safety factor, the belt slippage around the drive pulley, and motor torque rating into account to estimate the permitted acceleration $a_{\max}$:

$$a_{\max} = \min\left(a_{\max,tension}, a_{\max,slip}, a_{\max,heat}\right) \tag{1}$$

in which $a_{\max,\,tension}$, $a_{\max,\,slip}$, and $a_{\max,\,heat}$ are the maximum accelerations with consideration of belt over-tension risk, belt slippage risk and motor overheat risk, respectively. Then taking the acceleration profiles