Measurement 75 (2015) 230–243

Contents lists available at ScienceDirect

Measurement

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

Measurement of bulk material flow based on laser scanning technology for the energy efficiency improvement of belt conveyors

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ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 3 November 2014
Accepted 29 May 2015
Available online 8 June 2015

Keywords:
Non-contact measurement
Laser scanning
Bulk material flow
Belt conveyor
Energy efficiency improvement

ABSTRACT

Bulk material flow is the key variable of speed control technology and is responsible for the improving energy efficiency in belt conveyors. This paper presents the design and verification of a mathematical model intended for the measurement of bulk material flow on belt conveyor using laser scanning technology. This problem is solved using the method of non-contact measurement, which can acquire the surface profile of bulk materials moving on a belt conveyor in real-time using a laser scanner and a belt speed monitor. A contour extraction solution is proposed in accordance with the space's morphological characteristics and the material flow outline in one frame. By integrating the element areas of the bulk material cross section, a mathematical model to calculate the flow rate of bulk materials on moving belt is established. The main advantage of these models is that the measure accuracy is less affected that previous model by the uneven distribution and intermittence of bulk materials. The concept of the experimental rig at Wuhan University of Technology of China is designed so that it represents a 3.5 m long belt conveyor system on which bulk material flow detecting experiments can be conducted. When the belt operates at speed of 0.5 m/s, 1.0 m/s and 1.5 m/s, the repeatability, the correlation and the variation coefficient of the measurement value are more than 98%. The experimental results prove the excellent characteristics of the new device for real practice because the characteristics correspond to real operational conditions. The obtained results are useful for analysing belt mechanical properties under real operational conditions and for optimising operating procedures of belt conveyor systems.

1. Introduction

A belt conveyor is one of the most effective pieces of equipment for transporting bulk materials in many industrial sectors [1,2]. This is due to its high efficiency of continuous transportation compared with other means. The size and operation speed of these belt conveyors are specified so that their installed capacities meet or exceed the total energy consumption for real demand. Consequently, belt conveyors consume a considerable proportion of the total power supply during the material handling process as a result of the constant speed that is necessary for operation regardless of how much material there is on the belt [3]. The length and capacity increase, causing an increase in the installed power of these systems, which requires efficient energy improvement. It has been estimated that the energy efficiency

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http://dx.doi.org/10.1016/j.measurement.2015.05.041
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improvement of belt conveyors can save approximately 30% of the electrical energy needed and 20% of the maintenance cost [4]. Therefore, it is significant to recognise the influential factors of power consumption and to investigate energy saving methods for belt conveyor systems.

A belt conveyor is a typical energy system that converts electrical energy to mechanical energy. In principle three major options are available to reduce its energy consumption [5]. Firstly, the mechanical conveyor components like the idler rolls can be enhanced [6]. Secondly, the belt conveyor driver control method such as less motor operation [3], asynchronism motor Y–Δ switching [7], material flow automated control [8], soft-start devices addition can be used. Finally, the operational parameters or settings like the belt speed related to the belt loading degree can be optimised. In a nutshell, the energy efficiency of a belt conveyor can be improved at four levels: performance, operation, equipment and technology [9]. Generally, the energy efficiency improvement only at equipment level may inhibit the production capacity of bulk terminal or limit to certain scenarios because the belt conveyor is usually collaborated closely with other mechanical equipment [10]. Many papers have explored the effect of the optimisation of the operating parameters of belt conveyors. These studies were performed mostly by coordinating the energy-consuming factors of the belt speed and bulk material flow, which is the most efficient method of making the motor torque and load match well [11,12]. There are two categories of control strategies in the literature that can result in substantial reductions in power consumption, one relying on feeder discharging rates and the other one on belt speed. In practice, the two control strategies can be implemented manually or automatically. However, manual control can be error-prone because of the subjective criteria of the operator (even different operators due to shift work) and the potentially negative impacts that occur after a period of time, which degrades performance [13]. Thus, an optimisation strategy has been employed for the operating parameter control of a belt conveyor system. In [14], a dynamic programming approach for feeder discharge rate controlling was proposed and used for peak load management on gathering belts. Here, the regulation of the right motor speed to handle material on a belt has a large potential for optimisation. Saidur et al. [15] studied variable speed drives (VSDs) to improve the energy efficiency of belt conveyor systems and developed an electric motor system with VSD based on frequency control technology. To quantify the reduction in the energy consumption and cost savings due to the installation of the controller, a baseline was developed from actual data using regression analysis [16]. Ristic et al. [17,18] proposed a fuzzy logic control method to predict the reference speed of belt based on bulk material flow. Since detrimental vibrations may occur on the belt and conveyor construction at certain belt speeds when material flow fluctuates according to continuous speed control. Accordingly, discrete control could adjust the belt speed in a soft way. According to [19], the energy consumption of long distance conveyors was reduced by optimising the speed regulation control strategy, according to the different loading rates of the material divided by fuzzy logic. In recent years, a very long belt conveyor has been built with length of several dozen kilometers. The structure of the belt conveyor system is complex, and comprises a number of rollers, a belt, a drive pulley, a tail pulley, a vertical gravity take-up and a plate support [20]. Optimisations regarding efficient speed control require in-depth information about the whole system. In [21–26], the formulation of the optimisation problems of belt conveyor systems took the Time-of-use (TOU) tariff into account and considered other relevant constrains to achieve the minimisation of the energy consumption and energy cost. Then, a theoretical analysis along with experimental validation on the strategies of optimal switching control, model predictive control (MPC), single or multiple objective optimisation, and so on were shown for a coal-fired power plant system. The results showed that these strategies had the advantages of a remarkable energy-saving effect and had a broad application value. However, on the basis of DIN 22101, Lauhoff [27] and Song [28] questioned the appropriateness of speed control for the purpose of energy savings. The optimisation process has to fulfil the requirements of reliability and the high availability of the system. Therefore, careful consideration of the complicated dynamic characteristics of the mechanical system is a prerequisite of optimal speed control. Particularly, analysing the mechanics of driving a loaded belt is important for researching belt dynamic characteristics.

Bulk material flow, which is the key variable of speed control technology, must be accurately measured in real-time to apply current strategies scientifically and effectively. Some conventional approaches have been proposed to address the challenge of dynamic material measurement for a production audit, including an electric belt scale, a sonic distance metre and a nuclear belt scale [29–32]. These approaches employ either complicated constructions or inaccurate calibration processes for calculating of the unit weights of bulk material moving on a belt. They usually assume an ideal material distribution in the metering section. Subsequently, uncertainties in the real material distribution can lead to large errors, as it is a nonlinear function of the flow rate. These effects are particularly more important in the optimal range of the belt speed for energy efficiency improvement, wherein the belt speed increases by orders of magnitude according to small change in bulk material flow. Accuracy and precision, in addition to the operation effectiveness, are the main indicators of the quality of material flow measurement methods and systems. Unlike conventional methods, optical measurement technology can generate the data of the spatial coordinates of points from the scanned surfaces. Furthermore, with advantages such as a simple structure, low cost and high precision, optical measurement technology has been gradually used more often in quality or volume of material measurement [33–37]. In [38], Meng and Wang used the visual inspection system for coal image identification and coal amount estimation. Yuan et al. [39] designed a binocular vision system for weighing bulk material on a belt conveyor. Zhang et al. [40] proposed an improved method based on stereo cameras and a laser-line projector for a yard scan and local three-dimensional shape reconstruction. Zeng et al. [41] designed a visual inspection system