Belt Conveyor Speed Control Method Considering Elastic Constraint

Cheng Yan[1,2,a], Fei Zeng[1,2,b*] and Zhiqiang Li[1,2,c]

[1]Key Laboratory of Metallurgical Equipment and Control Technology, Ministry of Education, Wuhan University of Science and Technology, Wuhan 430081, China

[2]Hubei Key Laboratory of Metallurgical Transmission and Manufacturing Engineer, Wuhan University of Science and Technology, Wuhan 430081, China

[a]yancheng@wust.edu.cn; [b]zengfei2004@126.com; [c]2901176642@qq.com

*The Corresponding author

Keywords: Elastic Constraint; Belt conveyor; Speed control; PID controller

Abstract. In view of the current belt conveyor control methods, the speed is adjusted in a short time, and the sudden change of speed easily leads to the problem of tearing and slipping of the conveyor belt. A speed control method for the belt conveyor considering elastic constraints is proposed. The method considers the elastic constraint factors of the conveyor during transportation, analyzes the working process of the speed regulation scheme, and uses the *PID* controller to adjust the deviation of the whole control system, so that the speed control is consistent with the predetermined value. Through experiments, the effect is studied to ensure that the transportation energy consumption is reduced, the wear rate of the conveyor components is reduced, and the service life of the conveyor is prolonged.

Introduction

The metallurgical industry is one of the nine key energy-consuming industries in China. In recent years, outdated technical equipment, system mismatch, and backward control technology have become the fundamental reasons that restrict the development of energy-saving and emission-reduction technologies in the industry. Among the key equipment of metallurgical bulk material handling technology, the belt conveyor has the advantages of large loading capacity, economical reliability, convenient operation, etc. However, belt conveyor power is usually configured according to the maximum traffic volume. Most belt conveyor systems operate at constant speed regardless of the amount of material, resulting in low carrying efficiency and high energy costs.

The research found that the instantaneous flow rate adjustment of the belt conveyor on the conveyor belt has more energy-saving potential, which can save energy and reduce consumption. From the perspective of regulation, domestic and foreign professors have studied the control method to achieve the best loading efficiency of the belt conveyor, and provide the operator with the best solution. Ren zhongquan et al. [1] designed the belt conveyor control system based on fuzzy control theory for the uncertainty of the belt conveyor volume. Zeng fei et al. [2] proposed the design and verification of a mathematical model for measuring the flow of a belt conveyor body using laser scanning technology. Han Dongsheng et al. [3] proposed a speed-based energy-saving control method for belt conveyors to adjust the speed in a short time. A belt based on predictive control was proposed. Conveyor speed control energy saving method. Yin Jinfeng et al. [4] designed a speed control scheme based on ultrasonic coal flow monitoring, fuzzy algorithm, PLC frequency conversion control and other technologies for the problem that the belt conveyor is easy to cause power waste in low load state. Chen Xiangyuan et al. [5] studied the engineering background of the variable speed control principle and the intelligent speed regulation of the belt conveyor for the belt conveyor system with large power consumption, serious mechanical wear, and the belt conveyor speed and capacity cannot be reasonably matched. Control system design method. Jie Shijun [6] established a mathematical model of the tensioning device for the nonlinearity, large inertia, hysteresis and time-varying of the belt conveyor tensioning system, and proposed a

  DOI: 10.25236/icess.2019.222

correction link in series to eliminate the system oscillation. However, due to the complexity of the system structure and other factors, the practicality and effectiveness of the current system speed control strategy need further research. If the tensioning device is not effectively controlled, when the tension drops to a certain value, the conveyor belt will slip or even form a belt; if the tension is too large or there is a large change, the conveyor belt will be broken. Therefore, real-time and effective control of the tension control system of the tensioning device is of great significance for enhancing the safety and prolonging the service life of the belt conveyor. Based on this, this paper studies the control method of belt conveyor speed regulation by considering the elastic constraints in the transmission process. The method not only adjusts the belt conveyor to operate at a speed that matches its carrying capacity, but also reduces the power consumption of the belt conveyor.

Dynamic Equation of Conveyor Belt Considering Actual Load

Establishment of the Dynamic Equation of Conveyor Belt. The belt conveyor will produce irregular vibration during transportation, and the operation will be unstable or even jittery. Under the actual load, the belt conveyor speed and transportation volume are not matched reasonably and effectively, which will result in insufficient stability of the conveyor belt in the carrying section during the operation of the conveyor, causing damage to the roller set, wear and slippage of the conveyor belt, causing At present, the dynamic analysis of conveyor belts assumes that the materials are evenly distributed, which leads to deviations from the actual dynamic tension analysis. Therefore, it is necessary to consider the actual load during the transportation of the conveyor. In this paper, the Kelvin-Voigt model [7] is selected as the viscoelastic model of the conveyor belt. The discrete finite element model of the belt conveyor is established for the typical three-roller belt conveyor, the finite element method is used to divide the conveyor belt into units [8], as shown in Fig. 1. Assume that the length of the conveyor is L, change the distance from the center of the drum to the tensioning device L_1, take the position of the tensioning device as the origin, and the X direction of belt is positive.

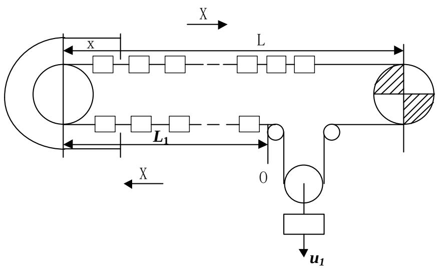

Figure. 1 System diagram of the belt conveyor

In Fig. 1, the microcell dx at the conveyor belt x is selected, and the force analysis is performed using the Kelvin-Voigt model, as shown in Fig. 2. Assume that the mass of each unit belt is m_i and the material on each unit is m_j.

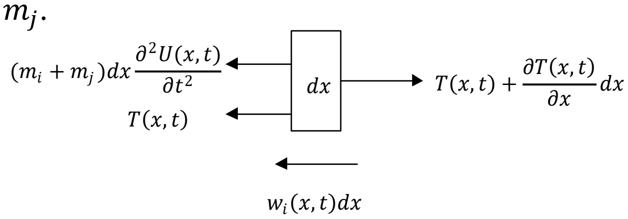

Figure. 2 Force diagram of the microcell on the conveyor belt

It can be obtained that the tension at x is $T(x,t)$, and the elastic displacement occurs as $u(x,t)$; the tension at x+dx is $T(x,t) + \frac{\partial T(x,t)}{\partial x}dx$, the elastic displacement that occurs is $u(x,t) + \frac{\partial u(x,t)}{\partial x}dx$. The inertial forces experienced on the microcell are $(m_i + m_j)dx\frac{\partial^2 U(x,t)}{\partial t^2}(i = 1,2)$.

When $i = 1$, the microcell is a conveyor belt carrying section, $m_{\text{cheng}} = (q_B + q_{RO})l_{\text{cheng}} + m_j$.

When $i = 2$, the microcell is the conveyor belt idle section, $m_{\text{cheng}} = (q_B + q_{RO})l_{\text{cheng}} + m_j$.

In the formula, q_B is the unit mass of conveyor belt; q_{RO} is the equivalent unit mass of the load bearing roller set; q_{RU} is the equivalent unit mass of the idle section idler set.

The equilibrium equation of the conveyor belt microcell is

$$\frac{\partial T(x,t)}{\partial x} = (m_{\text{i}} + m_j)dx\frac{\partial^2 U(x,t)}{\partial t^2} + w_i(x,t) \quad (1)$$

In the end you can get:

$$\frac{\partial T(x,t)}{\partial x} = (m_{\text{i}} + m_j)dx\frac{\partial^2 U(x,t)}{\partial t^2} + b_i\frac{\partial U(x,t)}{\partial t} + a_i \quad (2)$$

Establishment of Dynamic Equation of Tensioning Device. The tensioning device can provide a certain tension of the conveyor belt during the braking and normal operation of the belt conveyor, thereby avoiding the occurrence of unfavorable phenomena such as vibration of the conveyor, deviation of the conveyor belt and excessive sagging, and slippage of the driving drum. This paper establishes a model of a vertical heavy hammer tensioning device [9], as shown in Figure 3.

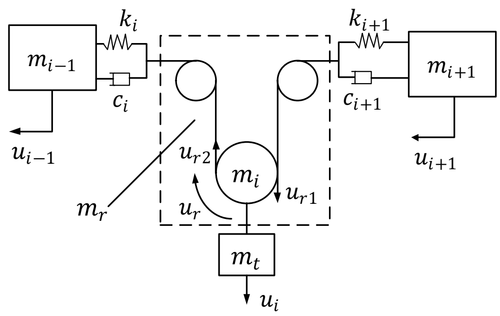

Figure. 3 Vertical weight tensioner

The tensioning drum in the device comprises two degrees of freedom of motion: a rotation u_r and a translational u_i in the vertical direction. According to the above situation, the expression can be derived from Figure 3.

$$\begin{cases} 2u_r = u_{r1} + u_{r2} \\ 2u_i = u_{r2} - u_{r1} \end{cases} \quad (3)$$

Finishing is available:

$$\begin{cases} u_{r2} = u_r + u_i \\ u_{r1} = u_r - u_i \end{cases} \quad (4)$$

In the formula: u_{r1} is the encounter point displacement of the conveyor belt and the tensioning device drum; u_{r2} is the displacement of the separation point of the conveyor belt and the tensioning device drum; u_r is tensioning the circumference of the device drum.

Belt Conveyor Discrete Model Dynamic Equation Matrix. The kinetic equations established by Equations (1) through (4) can be combined into a dynamic equation:

$$M\ddot{u} + C\dot{u} + Ku = F \quad (5)$$

In the formula: *M* is the quality matrix of the system; *C* is damping matrix of the system; *K* is the stiffness matrix of the system; *F* is external force matrix of the system; ü u̇ u are the acceleration, velocity and displacement of the system respectively.

The analysis shows that the mass matrix in the discrete model dynamics equation of the belt conveyor is a diagonal matrix of *N+M+4* steps:

$$M = \begin{bmatrix} m_i + m_1 & & & & & \\ & m_i + m_2 & & & & \\ & & \cdots & & & \\ & & & \cdots & & \\ & & & & m_i + m_{N+M+3} & \\ & & & & & m_i + m_{N+M+4} \end{bmatrix}$$

In the formula: $m_{\mathrm{cheng}} = m_i + m_j$, $j = 1, 2, 3 \cdots N$; $m_{\mathrm{N+M}}$、$m_{\mathrm{N+M+1}}$ —— tensioning device drum and weight quality;

Modeling Based on PID Control

In order to realize the PID control of the conveyor, a value is set in advance in each working process of the tensioning device. That is, the measured tensioning force of the conveyor belt, the tension of the conveyor belt during normal operation, and the transmission phase of the braking phase. The pressure of the cylinder is measured when tightening, and the above values can be obtained by experiments in advance. The magnitude of the force during PID control comes from the signal value that the force sensor feeds back to the D/A converter during tensioning of the tensioning device. The output of the PID control is used to control the pressure of the proportional valve in different stages to achieve precise adjustment of the hydraulic system pressure in these stages, and then to precisely control the tension of the conveyor belt [10]. Through simulation analysis, the speed, acceleration and dynamic tension of the conveyor under the conditions of start and brake can be obtained, which provides a reference for the whole machine design, parameter optimization and field application. Based on the existing experimental equipment, the conveyor is built as a Simulink model. The controller transmits control information to the simulation model through OPC communication and PLC given, and various status signals required by the controller are fed back to the controller through OPC communication. The belt conveyor simulation model was established as shown in Fig. 4 and the actual relevant parameters were used to carry out the conveyor.

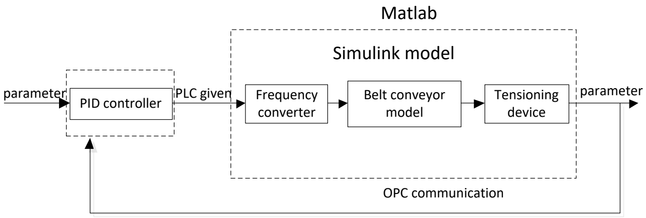

Figure. 4 Belt conveyor controller simulation system

In order to improve the stability of the conveyor starting process, reduce the starting time, reduce the dynamic tension and improve the dynamic performance of the system, this paper uses PID controller designed according to formulas (1) to (5) to control the conveyor starting process, as shown in Fig. 5.

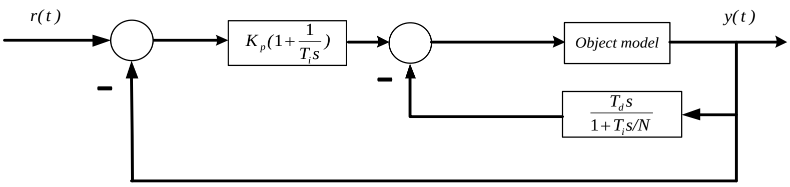

Figure. 5 PID structure

The PID controller is used to control the start-up process of the conveyor, and the start-up process can be reasonably controlled to achieve a smooth start and reduce the dynamic tension.

Conclusion

This paper studies the control method of belt conveyor speed regulation by considering the elastic constraints in the transmission process. For the problems in the process, the working process of the speed control scheme was analyzed. Through the analysis of the dynamic characteristics of the belt conveyor, the PID controller is used to control the starting process of the conveyor, and the starting process can be reasonably controlled to achieve the purpose of smooth starting and reducing the dynamic tension. The method makes full use of the carrying capacity of the belt conveyor and reduces the power consumption of the belt conveyor.

Acknowledgment

The authors would like to acknowledge the financial support provided by National Natural Science Foundation of China Youth Fund Project (Grant No. 61703215), the National Defense Pre-Research Project of Wuhan University of Science and Technology "Research on the cooperative control method of rigid-flexible coupled crawler transmission mechanism under transient conditions", the Hubei University College Students Innovation and Entrepreneurship Training Program “Internet + Belt Conveyor Energy Efficiency Online Monitoring System”. Nantong University - Nantong Intelligent Information Technology Joint Research Center Open Project KFKT2016A10).

References

[1] Zhongquan ren, Miao wang, Design of Energy-saving Speed Control System for Belt Conveyor [J]: Coal Mine Electromechanical and Information, Vol. 35 (2016) No.5 p230-243.

[2] Fei zeng, Qing Wu, Xiuming Chu, Zhangsi Yue, Measurement of Bulk Material Flow Based on Laser Scanning Technology for the Energy Efficiency Improvement of Belt Conveyors[J]: MEASUREMENT, Vol. 75 (2015) p230-243.

[3] Dongsheng Han, Yonggui Du, Yusong Pang, Tiezhu Qiao and Gaowei Yan, Belt Conveyor Speed Regulation and Energy Saving Method Based on Foresight Control [J]: Industrial Automation, Vol. 44 (2018) No.6 p64-68.

[4] Jinfeng Yin, Yin Gao, Speed Control of Belt Conveyor Based on Coal Flow Monitoring [J]: Mechanical Management Development, (2018) No.6 p84-85.

[5] Xiangyuan Chen, Design of Intelligent Speed Control System for Belt Conveyor [J]: Coal Mine Machinery, Vol. 37 (2016) No.11 p21-23.

[6] Shijun Jie, Xiaoyan Xiong, Bing Wu and Diandian Liu, Research on Belt Conveyor Tensioning Device and Common Tension Control System [J]: Industrial Automation, Vol. 44 (2018) No.2 p 90-95.

[7] Jianhua Li, Song Zhao, Research on Modeling Method of Belt Conveyor Based on AMESim [J]: Coal Mine Machinery, Vol. 35 (2014) No.9 p 45-47.

[8] Lin Cui, Finite Element Model Analysis of Belt Conveyor Tensioning Device [J]: Mechanical Research and Application, (2015) No.5 p 26-28.

[9] Zhanfang Xiao, Research and Analysis of Dynamic Characteristics of Belt Conveyor Based on AMESim [D]. Taiyuan: Taiyuan University of Science and Technology, 2013.

[10] Yankun Zhu, Wenguo Li, Research on Control of Belt Conveyor Tensioning Device Based on PID Algorithm [J]: Coal Mine Machinery, Vol. 35 (2014) No.5 p61-62.