ATLANTIS PRESS Journal of Robotics, Networking and Artificial Life, Vol. 4, No. 2 (September 2017) 175–178

Fuzzy self-tuning PID control algorithm for belt conveyor driven by multi-motor

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Abstract

Aiming at the problems of low efficiency when long distance and high-inclination belt conveyor driven by multi-motor is in light or idle run as well as electrical power unbalance. Control strategy for belt conveyor driven by four-motor via fuzzy self-tuning PID control algorithm was proposed. The Speed setting algorithm of belt conveyor and fuzzy self-tuning PID algorithm for speed control and power balance control are introduced. The application shows that, according to the coal flow changes of the belt conveyor in real-time, the speed can be automatically adjusted through this algorithm, making the power of the four motors convergence both speed control error and the power control error of which are lower than 2.6%.

Keywords: belt conveyor, power unbalance, fuzzy self-tuning PID

1. Introduction

In order to ensure the safe and stable operation of the transport aircraft, the following problems need to be solved: (1) Mechanical damage of the equipment due to the heavy load and the dynamic tension of the tape during start-up and stopping; (2) Running state power consumption problem; (3) Multi-motor power balance problem. For the above problems, scholars at home and abroad have also carried out researches, but mostly for the smaller angle (35 °and below): Reference 1 uses direct torque control strategy to achieve motor power balance control with fast response and good stability, which is directly affected by the motor parameters. In Reference2, what is proposed is a power balance control strategy for mine belt conveyor motor based on torque

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compensation. The vector dual closed-loop controller is a conventional PI controller, and its adaptability is not strong. Reference 3 uses the current control method to regulate the power balance of the belt conveyor, when the current of each motor exceeds or falls below 5% of the average current. Because of the characteristics of large inertia and severe hysteresis, the belt conveyor with multi-motor drive is a time-varying and nonlinear control object, It is difficult to adopt conventional fixed-parameter PID control to achieve good control effect; when a single fuzzy controller is used, the response speed is high, but its control accuracy is difficult to meet the requirements. This paper proposes a fuzzy control algorithm based on fuzzy self-tuning PID control algorithm for large-angle mining belt conveyor driven by multi-motor, achieving flexible starting and stopping of belt conveyor, adjusting the speed according to the size of the load automatically, and maintaining multi-motor power balance.

2. The general control model of high-inclination belt conveyor

Aiming at the problem of mechanical damage to the equipment caused by the falling or rolling of the material (coal) during the heavy load start and stop of the belt conveyor and the dynamic tension, the excessive wear and energy wastage of the mechanical transmission mechanism under light load or no load high speed running condition and dynamic balance of motors, this paper proposes the overall control model of the belt conveyor shown in Fig.1. The control system is mainly composed of speed setting module, speed control module, power balance control module and so on. It adopts double closed-loop structure. The inner loop is composed of the power balance controller. The strategy is using the master-slave control mode, namely, taking the current of the 1# motor as the given value of the current of 2# ~ 4# motor. When the current of 2# ~ 4# motor is not consistent with the No. 1 motor, the power balance fuzzy controller can change the output of the motor by automatically adjusting the opening of the servo proportional valve of the 2# ~ 4# controllable driving device CST, so as to realize the four motor power balance control. The outer ring is composed of a speed control module, and its function is to realize the belt speed control. The basic principle is comparing the tape speed with the given speed. When the belt speed and the given speed is inconsistent, the controller first adjust 1# CST servo proportional valve opening step by step to change the output of 1# motor, then the other three motors automatically tracking the output power of 1#motor , so four CSTs work together to achieve the adjustment of the belt speed. The function of the speed setting module is to determine the speed of the tape during starting, stopping and normal operation according to the coal flow rate in the belt.

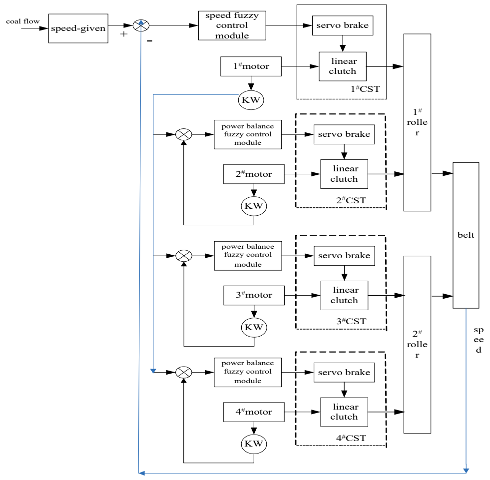

Fig.1 Belt speed and motor power balance control principle

Speed control module and power balance control module both use fuzzy self-tuning PID control algorithm, and its structure is shown in Fig.2. It is composed of a fuzzy controller and PID controller. The PID controller mainly realizes the speed and power balance control of the double drum four-drive belt conveyor. The fuzzy controller is mainly used to monitor the control effect and adjust the parameters of the PID controller. By monitoring the tape machine speed and motor power (current) deviation e and the deviation change rate ec continuously, the control effect can be analyzed. Improving the control effect of double-drum four-drive belt conveyor control system is achieved by adjusting the proportion coefficient, integral coefficient and differential coefficient of PID controller using fuzzy reasoning. Speed control fuzzy self-tuning PID input is speed deviation e and speed deviation rate of change ec; three power balance control fuzzy self-tuning PID input are current deviation e and current deviation Rate of change ec of 2# ~ 4# motor and 1# motor. Fuzzy self-tuning PID output are the respective controllable drive CST servo proportional valve opening.

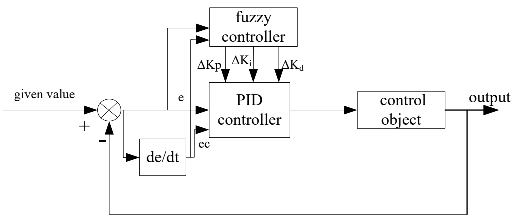

Fig.2 The fuzzy self-tuning PID principle diagram

PID controller uses incremental operation, position output, and the formula is shown in (1), (2), (3).

In the formulas (1) to (3): U (k) is the output of the controller (also called the regulator)

$$\Delta u(k) = u(k) - u(k-1) = K_p ec(k) + K_i e(k) + K_d[ec(k) - ec(k-1)] \quad (1)$$

$$u(k) = u(k-1) + \Delta u(k) \quad (2)$$

$$ec(k) = e(k) - e(k-1) \quad (3)$$

First, apply the simulation tools and experimental methods offline. According to the principle of fuzzy control, establish on-line adjust table of PID controller's proportional(fuzzy decision table), including coefficient increment ΔK_p, integral coefficient ΔK_i differential coefficient ΔK_d and store them in the PLC controller memory for fuzzy on-line reasoning query controller. In the control process, the fuzzy controller applies fuzzy reasoning to find out the corresponding adjustment table (fuzzy decision table) from ΔK_p, ΔK_i and ΔK_d according to the deviation e and deviation change rate ec (de/dt) (4), and get the PID three parameters K_p, K_i and K_d setting value. Finally, adjust the K_p, K_i and K_d to the PID controller.

$$\begin{cases} K_P = K'_P + \{E, E_C\}; & K_P = K'_P + \Delta K_P \\ K_i = K'_i + \{E, E_C\}; & K_i = K'_i + \Delta K_i \\ K_d = K'_d + \{E, E_C\}; & K_d = K'_d + \Delta K_d \end{cases} \quad (4)$$

In the formula (4), K'_p, K'_i and K'_d are the initial pre-setting values of K_p, K_i and K_d obtained through the traditional PID parameter setting method.

3. Speed setting of tape conveyor

In order to reduce the loss of mechanical transmission mechanism and improve the efficiency of the motor, the belt conveyor should operate at the speed in accordance with the speed of its coal flow. At the same time, in order to prevent damage caused by impact on the tape from frequent changes of tape speed, control system set six speed diagrams. When the belt is overhauled (no load), the speed is 0.25m/s; when the coal flow rate is less than or equal to 120t, the speed is 0.65m/s; the coal flow rate is more than 120t and less than or equal to 240t, the speed is 1.35m/s; the coal flow rate is more than 240t and less than or equal to 360t , the speed is 2.00m/s; the coal flow is greater than 360t less than or equal to 480t, the speed is 2.55m/s; the coal flow is greater than 480t less than or equal to 600t , the speed is 3.15m/ s.

In order to reduce the impact on the grid caused by starting current of four drive motors, reduce the mechanical damage to the equipment caused by dynamic tension because of starting and stopping of high-angle tape conveyor, and avoid the material decline or rolling when start, the speed curve of belt starting and stopping should use "S" type speed diagram, as shown in Fig.3.0~t_3 is the starting acceleration phase of the belt conveyor; t_3~t_4 is constant speed running section; t_4~t_7 is the deceleration stage; t_4~t_5 is the early deceleration stage; t_5~t_6 is the constant deceleration stage; t_6~t_7 is the final deceleration stage of the belt conveyor: the acceleration of the tape machine can be set at 0.1 m/s^2 to 0.3 m/s^2 at the time of starting and stopping, and the starting time is controlled in 60s~200s, and both can be set according to site requirements.

$$V_1(t) = \frac{1}{2}k_1 t^2 \quad (5)$$

$$V_2(t) = \frac{1}{2}k_1 t^2 + a_{mq}(t - t_1) \quad (6)$$

$$V_3(t) = \frac{1}{2}k_1 t^2 + a_{mq}(t_2 - t_1) + \frac{1}{2}k_2(t - t_2)^2 \quad (7)$$

In the formulas (5) to (7):k_1 (m/s^3) is the change rate of the acceleration in the stage 0~t_1; k_2(m/s^3) is the change rate of the acceleration in the stage t_2~t_3. a_{mq} (m/s^2) is the maximum acceleration in acceleration section;

$$V_1(t) = V_m \quad t_4 < t \le t_5 \quad (8)$$

$$V(t) = V_m - \frac{1}{2}k_3(t - t_4)^2 \quad t_4 < t \le t_5 \quad (9)$$

$$S(t) = V_m(t - t_4) - \frac{1}{6}k_3(t - t_4)^3 \quad (10)$$

$$V(t) = (2a_{mz}S + V_6^2)^{\frac{1}{2}} t_5 < t \le t_6 \quad (11)$$

$$V(t) = V_6 - \frac{1}{2}k_{z4}(t - t_6)^2 \quad t_6 < t \le t_7 \quad (12)$$

In the formulas (8) to (12): a_{mz} (m/s^2) is the maximum acceleration in the starting acceleration stage; S(t)is the travel in the constant deceleration stage(m);k_{z4} （m/s^3） is the change rate of acceleration in stage t6~t7.

4. Experimental analysis

Based on the designed speed and power, the belt conveyor control system of balance adaptive fuzzy PID control algorithm has actually operated, with the actual control curve speed and power of the belt conveyor shown in Figure 3. In the figure, the belt start-up time is 180s, the belt speed is fixed at 3.15m/s. Once the belt runs stably, the running speed will change from 3.20m/s to 3.10m/s, and the control error will be less than 2.6%. The operating current fluctuates within the range of 20.5A~21.5A, and the control error is less than 2.6%, which realizes the reliable, safe and energy-saving operation of the main shaft belt transport system.

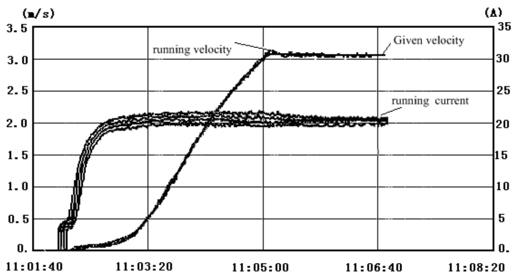

Fig.3 System speed and power curve of actual control

5. Conclusion

(1) "S" speed profile is applied as speed profile in the belt conveyor's starting and stopping, thus preventing the material (coal) from dropping or rolling during the start and stop of the heavy-duty conveyor, and the mechanical damage to equipment caused by the dynamic tension of the tape during start and stop, so as to improve the safety performance of equipment and operators.

(2) According to the size of the coal flow, the speed of the belt conveyor is divided into 6 steps. The fuzzy self-tuning PID algorithm is used to control the speed of the belt conveyor, so the speed control error is less than 2.6%.

(3) Use the master-slave control mode and take the current of the 1# motor as a given value. The fuzzy self-tuning PID control algorithm makes the current of the 2#~4# motor follow the current of the 1# motor, so the control error is less than 2.6%. This realizes high control precision so that the powers of four drive motors are almost balanced or the difference is controlled within an allowable range. By doing so, we prevent the occurrence of motor burnout, improve the safety and reliability of the system, and extend the life of the belt conveyor.

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