THE APPLICATION OF CROSS LIMIT CONTROL ON SPEED ADJUSTABLE BELT SCALE SYSTEMS

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ABSTRACT

Weight belt feeders are widely used in industrial applications to transport solid materials into a manufacturing process at a selected feed rate. A weight belt feeder system consists of several belt conveyors with different weight ratios. In normal operations, each of belt conveyor has its own reference feed rate without any relation with each other. Obviously, in this case, if the velocity of any belt conveyor does not match a desired speed for some reason while the others are still in corrected operation then its feed rate is not kept at the expected value. The imperfection work of the belt scale happened in a sufficient time will lead to a wrong mixed component of the materials and defective production. In this paper, we propose a cross limit control method on speed adjustable belt scale systems, in which if the flux rate of any belt conveyor does not guarantee and it exceeds a given limit then the setpoints of the others belt conveyors will be regulated so that the feed rates of all belt conveyors will be increased or decreased with the same percentage. The application of this method in speed adjustable belt scale systems will maintain the mixture ratio at a predesigned value and improve the quality of productions. The effectiveness of the proposed method will be demonstrated via some simulation results.

Key words: *Cross limit control, belt scale, induction machine, PID controller, converter*

INTRODUCTION

Belt conveyor scales are widely used in many industrial areas such as food, chemical, or metal manufacturing process. A speed adjustable belt scale shown in Fig. 1 consists of a weight measurement sensor (loadcell), a speed control unit with an electrical motor and drive, a belt speed measurement structure. The continuous conveyor belt scales (or continuous weighing devices) keep the material flux at a constant feedrate in kilograms per second (or Ton per hour). The detail of a working principle of a belt conveyor can be found in [1].

In the literature, the study in [2] focuses on the application of speed control to belt conveyors for the purpose of reducing energy consumption of belt conveyors with the help of a dynamic belt model. In [3], a linear model of a belt conveyor is built to calculate the conveyor dynamic performance in transient period, both in acceleration and deceleration operations. In [4], a gain-scheduled PI-like fuzzy logic controller and a self-tuning PI-like fuzzy logic controller are designed for a belt conveyor system to maintain a constant feed rate. A performance comparison of these controllers is also given in this paper. In [5], a weight system including the measurement method to measure the mass with a maximum error of 1% is presented. The test results and the recommendations for future works are also given.

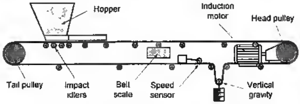

Fig. 1. *Belt scale structure [2],[6]*

Let Q_{Σ}^{ref} be the reference of the total feed rate (measured in Ton per hour). Let C_i be the component percentage of each material. Let Q_i^{ref} be the set point for the i-th belt conveyor rate. We have $Q_i^{ref} = C_i Q_{\Sigma}^{ref}$ (1)

Let v_i be the speed of the i-th belt conveyor, the weight of the bulk material on $1m$ length of the i-

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Tel· 0913 286461, Email: h.nguyentien@tnut.edu.vn th belt is denoted by w_i. The flux rate of the belt conveyor is

$$Q_i = w_i v_i \tag{2}$$

Assume the belt scale system consists of N belt conveyors. The total flux of these belt conveyors is

$$Q_\Sigma = \sum_{i=1}^{N} Q_i \tag{3}$$

The error of the desired feed rate and the actual one is $e_i = Q_i^{ref} - Q_i$. This error will be minimized by using a flow rate controller as shown in Fig. 2. The speed of the belt is regulated by controlling the speed of the induction motor as a prime mover.

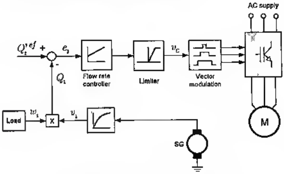


Fig. 2. *Belt scale control system*

In the normal operation of a continuous weight belt feeder system, the belt speed of each conveyor is regulated in order to keep the variable material feeding rate at a desired value regardless the variations of the material distribution and weight along the belt length. However, since there is no link between the flux references, if the flux of any belt scale cannot be kept at an expected value for some reasons then the component percentage of this material and, therefore, the mixture ratio does not guaranteed anymore. As it is illustrated in Fig. 3, assuming that the flux of i-th belt scale Q_i has a big difference from it reference value Q_i^{ref}. This can be happen sometime because of the fact that, for instance, the material is stuck in the batching hopper. At the moment, the component percentage of this material $C_i' = \frac{Q_i}{Q_i^{ref}}$ also has a big difference from it reference value $C_i = \frac{Q_i^{ref}}{Q_\Sigma^{ref}}$. This might lead to a low quality production output.

In order to maintain the mixture ratio of the production line, we present in this paper a cross limit control method for a speed adjustable belt scale. The theory of the cross limit control is in the setting values of the flux rates, in which, the flux rate of any material only allows to reach its upper or lower limit if the other materials are within the limiting range. If we assume that the continuous weight belt feeder system consists of two belt scales as shown in Fig. 4 then this control the structure is called the double cross limit control system [7]. In this configuration, the upper and lower limits determined by the second belt scale are added in the double cross limit block, which result in flux rate of the first belt scale is increasing or decreasing only within the limiting range. Similarly, the upper and lower limits determined by the first belt scale are added in the double cross limit block, which result in flux rate of the second belt scale is increasing or decreasing only within the limiting range.

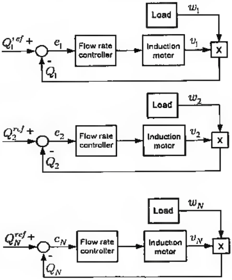


Fig. 3. *A continuous weight belt feeder system with N belt scales*

The cross limit control of a continuous weight belt feeder system with more than two belt scales is implemented in similar way and it will be discussed in the next section.

CROSS LIMIT CONTROL

Let us denote $\tilde{Q}_k$ as the set point of the flux rate of the i-th belt conveyor with cross limit utilization, δ_h and δ_l as high and low flux rate limits of the i-th belt conveyor. The set point for the flux rate of the belt scale is

$$\tilde{Q}_k = Q_k^{ref} \qquad (4)$$

if $\delta_l < \dfrac{Q_i - Q_i^{ref}}{Q_i^{ref}} < \delta_h$, and

$$\tilde{Q}_k = Q_k^{ref}\left(1 + \sum_{\substack{i=1 \\ i\neq k}}^{N} \frac{Q_i - Q_i^{ref}}{Q_i^{ref}}\right) \qquad (5)$$

if $\dfrac{Q_i - Q_i^{ref}}{Q_i^{ref}} < \delta_l$, or $\dfrac{Q_i - Q_i^{ref}}{Q_i^{ref}} > \delta_h$, where $i = \{1,\ldots,N\}$, Q_i is the actual flux of belt scale number i, Q_i^{ref} is the reference value of the flux rate of belt scale number i.

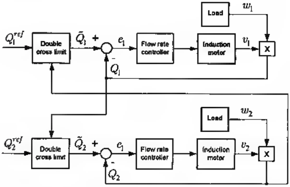


Fig. 4. *A double cross limit belt scale control system*

Alternatively, we can rewrite equation (5) as follows

$$\tilde{Q}_k = Q_k^{ref}\left[1 + \sum_{i=1}^{N}\left(\frac{Q_i - Q_i^{ref}}{Q_i^{ref}} - \frac{Q_k - Q_k^{ref}}{Q_k^{ref}}\right)\right] \qquad (6)$$

Equation (6) is used to implement the cross limit control for a continuous weight belt feeder system. The control structure is shown in Fig. 5.

SYSTEM MODELLING

Modeling of an induction machine

In a dq reference frame that has the d axis coinciding with the rotor flux, the induction machine model can be described by [8]

$$\begin{aligned} \dot{x}_r &= A_r x_r + B_s v_s + B_r x_r \omega_s \\ y_r &= C_r x_r \end{aligned} \qquad (7)$$

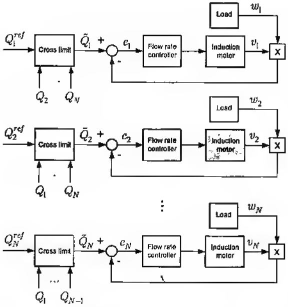


Fig. 5. *Belt scale system with cross limit control*

where $x_r = \left[i_{sd} \quad i_{sq} \quad \Phi_{rd} \quad \Phi_{rq}\right]^T$, $v_s = \left[v_{sd} \quad v_{sq}\right]^T$, $v_r = \left[v_{rd} \quad v_{rq}\right]^T$, $y_r = i_r = \left[i_{sd} \quad i_{sq}\right]^T$ with v_{sd}, v_{sq}, v_{rd}, v_{rq}, i_{sd}, i_{sq}, i_{rd}, i_{rq} denoting the voltage and current components of the stator and rotor, respectively, and Φ_{rd}, Φ_{rq} being the rotor flux components,

$$A_r = \begin{bmatrix} a_{r11} & 0 & a_{13} & a_{r14} \\ 0 & a_{r11} & -a_{14} & a_{r13} \\ a_{31} & 0 & a_{r33} & a_{r34} \\ 0 & a_{r31} & -a_{r34} & a_{r33} \end{bmatrix}$$

$$B_s = \begin{pmatrix} \dfrac{1}{\sigma L_s} & 0 \\ 0 & \dfrac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{pmatrix}, \quad B_r = \begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

with $a_{r11} = -\left(\dfrac{a+1}{T_s} + \dfrac{a}{T_r}\right)$, $a_{r13} = \dfrac{a}{L_m T_r}$, $a_{r14} = \dfrac{a\omega_m}{L_m}$, $a_{r31} = \dfrac{L_m}{T_r}$, $a_{r33} = -\dfrac{1}{T_r}$, $a_{r34} = -\omega_m$; here L_s, L_r are the stator and rotor inductances, L_m is the mutual inductance, R_s, R_r are the stator and rotor resistances, $\sigma = 1 - \frac{L_m^2}{L_s L_r}$ is the total linkage coefficient and $a = \frac{1-\sigma}{\sigma}$; moreover $T_s = \frac{L_s}{R_s}$ and $T_r = \frac{L_r}{R_s}$ denote the time constants of the stator and rotor, ω_m is the mechanical angular velocity of the rotor, and ω_s is the electrical angular velocity of the stator (or grid).

Simulink model of the controlled system

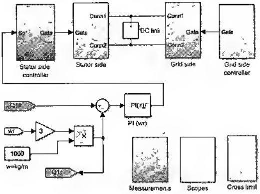


Fig. 6. *Simulink model*

The Simulink model of the controlled system with a cross limit unit is shown in Fig. 6. This model is employed to test the effectiveness of proposed method for six reference fluxes ($N = 6$). However, for sake of simplicity, the model is only developed for only one induction machine drive of the first belt scale. Other induction machine drives can be developed in the same fashion. The stator side includes the flux control loop with a PI flux controller, the speed control loop with a PI speed controller and a stator converter. The role of the stator side control loops is to keep the flux rate of the belt conveyor at the reference value by controlling the speed of the induction motor. The grid side consists of a grid side controller and converter. The grid side control is to maintain the DC-link voltage at a constant value.

The model of the cross limit unit is shown in Fig. 7 based on equations (4) and (6).

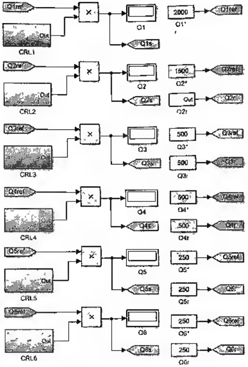
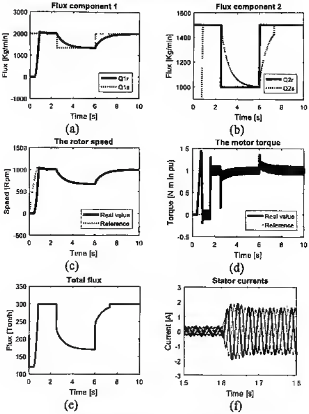


Fig. 7. *Cross limit block*

SIMULATION RESULTS

The following tests are implemented with an induction machine whose parameters are given in Appendix A.

The simulation results are shown in Fig. 8. In this test, the upper limit δ_h is 5 and the lower limit δ_l is -5%. As shown in Fig. 8b, the actual flux of the second belt scale is suddenly decreased from 1500 Kg/min (90 Ton/h) to 1000Kg/min (60Ton/h) at 2.5s for some reason while the actual flux of the first belt scale still tracks its reference well (in between ± 5% of the limit range). Because of the cross limit reaction, the set point for the flux rate of the first belt scale is reduced from 2000Kg/min (120Ton/h) to 1333Kg/min (79.98Ton/h) as shown in Fig. 8a. Note that, in this situation, the reference values of the fluxes for the first and second belt scales are not changed. At 6s, the actual flux of the second belt scale is recovered its normal value from 1000Kg/min (60Ton/h) to 1500Kg/min (90Ton/h) as it can be seen in Fig. 8b. Once again, thanks to the cross limit reaction, the set point for the flux rate of the first belt scale is increased from 1333Kg/min (79.98Ton/h) to 2000Kg/min (120Ton/h) as shown in Fig. 8a. It should be emphasized that if the actual fluxes of all belt scales are inside the limit range then the cross limit has no action on the set point of any belt scale.



(a) (b) (c) (d) (e) (f)

Fig. 8. *Simulation results*

When the set point for the flux of the first belt scale is changed, the set point for the rotor speed of the induction machine is also changed. As it can be seen from Fig. 8c, the actual speed of the induction machine follows its reference value quickly. This indicates a good quality of the speed control loop of the induction machine.

The electrical torque, the total flux, and the stator currents of the induction machines are shown in Fig. 8d, 8e, and 8f, respectively.

CONCLUSIONS

The cross limit control applied to a speed adjustable belt scale system has been implemented in order to maintain the mixture ratio of the production line at a constant value. In some situations, one of the belt conveyors might not workat anadequate accuracy.When the error between the actual flux and the desired one is bigger than a limited range, the set points of the other belt conveyors arere-calculated so that the feed rates of all belt conveyors will be increased or decreased with the same percentage. The simulation results show that, in the speed adjustable belt scale systems with cross limit control, the mixture ratio are kept at a predesigned value.Therefore, quality of products will be improvedsignificantly.

APPENDIX A

INDUCTION MACHINE PARAMETERS

Stator resistance R_s	0.0139 p.u.
Stator leakage inductance L_{1s}	0.0672 p.u.
Rotor resistance, referred to the stator side R_r	0.0112 p.u.
Rotor leakage inductance, referred to the stator side L_{1r}	0.0672 p.u.
Magnetizing inductance L_m	2.717 p.u.
Rotor inductance L_r	$L_{1r}+L_m$
Stator inductance L_s	$L_{1s}+L_m$
Moment of inertia H	0.2734 s
Friction coefficient F	0.0106 p.u.
Number of pole pairs p	2

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TÓM TẮT

ỨNG DỤNG ĐIỀU KHIỂN GIỚI HẠN CHÉO TRONG CÁC HỆ THỐNG CÂN BĂNG ĐIỀU TỐC

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Các hệ thống cân băng định lượng được sử dụng rộng rãi trong các ứng dụng công nghiệp để vận chuyển các nguyên liệu thô trong các dây chuyền sản xuất với lưu lượng đặt trước. Một hệ thống cân băng định lượng bao gồm một số các băng tải với các hệ số tải khác nhau. Trong quá trình bình thường, mỗi cân băng có riêng một lưu lượng đặt trước và không có sự liên quan với các cân băng khác. Rõ ràng là, trong trường hợp này, nếu vì một lý do nào đó tốc độ của một trong các băng tải không đạt được giá trị mong muốn trong khi các băng tải khác vẫn đang hoạt động đúng sẽ làm cho lưu lượng của băng tải đó không giữ được giá trị đặt trước. Sự làm việc không hoàn hảo của một cân băng trong một thời gian đủ lớn sẽ dẫn đến sai lệch tỷ lệ phối liệu và tạo ra các phế phẩm. Trong bài báo này chúng tôi đề xuất phương pháp điều khiển giới hạn chéo cho các hệ thống cân băng điều tốc, trong đó nếu lưu lượng thực tế của một cân băng không được đảm bảo và vượt quá một giới hạn cho trước thì điểm đặt của các lưu lượng của các băng tải còn lại sẽ được điều chỉnh sao cho tất cả lưu lượng của các băng tải sẽ được tăng hay giảm với cùng một tỷ lệ phần trăm. Việc áp dụng phương pháp này trong các hệ thống cân băng định lượng điều tốc sẽ duy trì tỷ lệ phối liệu theo đúng giá trị đặt trước và góp phần nâng cao chất lượng sản phẩm. Hiệu quả của phương pháp này sẽ được minh họa thông qua một số kết quả mô phỏng.

Từ khóa: *Điều khiển giới hạn chéo, cân băng, động cơ không đồng bộ, bộ điều khiển PID, bộ biến đổi*

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