Multi-level dosing and preact self-adaption correcting automatic batch control model

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Abstract

The process flow and system structure of automatic batch weighing system are presented. In order to increase production speed and dosing accuracy, the multi-level dosing control model (high/low speed dosing + inching dosing) is designed. Besides, the inching dosing mode is adopted to accurately compensate the weight deviation. In order to solve the problem that the fall of materials in-air cannot be easily controlled and out of tolerance. The multi-level dosing control model and preact will correct after each dosing dynamically with iteration method, moreover, the target value is predicted with second-order estimator, so as to increase the dosing speed with high weighing accuracy. The successful application proves that the control model can realize the rapid and accurate control of batch weighing process and has quite favourable control and reliability.

Keywords: Automatic batch, Multi-levels dosing, Fall of dosing, Self-adaption correcting, preact

1 Introduction

Automatic batch weighing system [1] is a very important procedure for the meticulous factory production technology. Velocity and accuracy of the batch weighing [2] is vital for the efficiency of entire production line and the product quality [3]. Automatic batch control process is a multiple inputs & outputs system. Various batch-conveying lines will be coordinated and controlled as per the formulating ratio set in advance [4]. Control system shall realize timely and accurate monitoring and regulation of material level and flow. This system will adopt two-level dosing control modes, respectively high/low speed and inching dosing. The two-level dosing control model and the preact will be corrected after each dosing dynamically with iteration method, moreover, the target value is predicted with second-order prediction, so as to realize the dynamic correction [5] of every dosing process and improve the dosing speed with high weighing accuracy.

2 Process Flow and Control Principles of the System

This system is mainly comprised of 8 large silos, 10 small silos, 8 liquid silos, 1 artificial dosing silo, 4 sets of weighing hoppers and weighing instruments (W1-W4), three sets of dosing vibrating screens (B1-B3), three sets of vibrating screen drivers (M1-M3), mixer (M5) and conveyor (M6) (as shown in Figure 1).

The system will firstly select the type of auxiliary materials to be dosed and calculate the material weight required for each silo according to the requirements for ingredients of feeds produced at present, and then come into operation after being confirmed by the operator. Large & small silos, artificial dosing silo and liquid silo shall set value as per the formulation of each silo. Start up the electromagnetic vibrating feeders (vibration velocity is in direct proportion to the dosing speed) as per the sequence set for dosing and feed solid materials into the hopper for weighing. When materials in the hopper reaching the set value, vibrating feeder will stop and the material feeding and weighing in the next silo will be done in sequence. After completing the weighing in all silos, solid materials in each hopper will be placed into the mixer through vibrating screens (M1, M2 and M4), for primary mixing. During that process, vibrating screen of the liquid silo (M3) will then feed liquid materials into the mixer for secondary mixing. Finally, the conveyor will move out the uniformly mixed feeds and the automatic batching process [6] completes.

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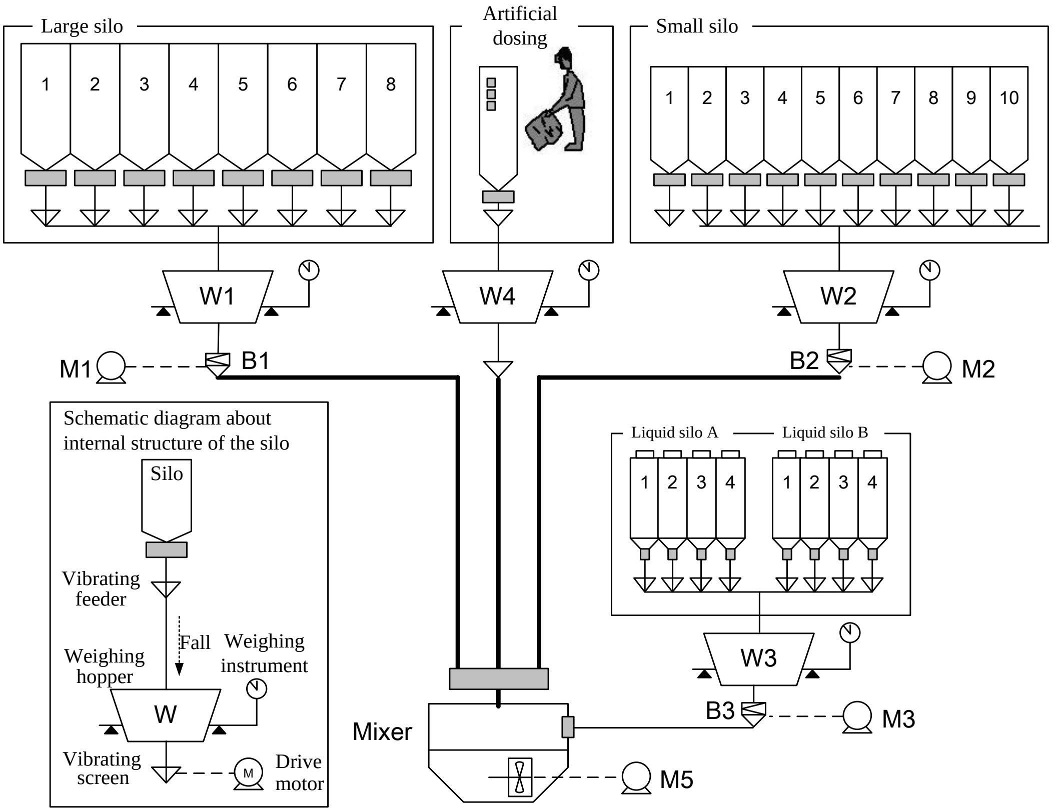

FIGURE 1 Control system process chart

Vibrating feeder is installed at the silo bottom. Vibrating feeder should be started at the beginning of the weighing process and materials will drop from silo to the weighing hopper. Since a certain distance exists between the silo bottom and the weighing hopper [7], materials will fall into the weighing hopper after a certain delay in the air after the vibrating feeder activates and only then weight of materials in the hopper will change. When vibrating feeder stops, all residual materials in the air will only fall into the hopper after a certain delay and then weight of materials in the hopper will be stable. Such out-of-tolerance caused by lagged materials is named as "fall of dosing" [8]. In addition, material level in the silo will fluctuate due to irregular shape of materials, relatively great difference in grain size and unscheduled dosing into silo during the production. Therefore, flow velocity of material changes randomly at every moment, to make the deviation of material weighing caused by "fall of dosing" change [9] every time. This weighing deviation caused by changes in material level and fall of dosing shall be provided with special batch weighing correction model. When weighing is going to be completed, estimate and calculate the preact as per the "fall of dosing" [10]; stop dosing when it reaches the preact; make use of the inertia before stop to realize:

"Current weighing value + Estimate preact = Target weighing value", and to control the error of dosing within the target ± threshold value.

3 Hardware Structure and Control Principles of the System

A three-level computer control network is comprised of the HMI, PLC, weighing instrument and frequency converter (as shown in Figure 2). PLC connects to the frequency converter through field bus and to the weighing instrument through RS232 serial. During the automatic batch production process, mix the main materials in the large silo, auxiliary materials in the small silo, artificial and liquid materials as per a certain proportion, and complete the measurement of materials by the weighing hopper. PLC mainly realize the real-time control of conveyor, weighing and mixing processes; complete the system fault detection, display and alarm; and meanwhile send signal to the frequency converter to regulate the speed of belt conveyor.

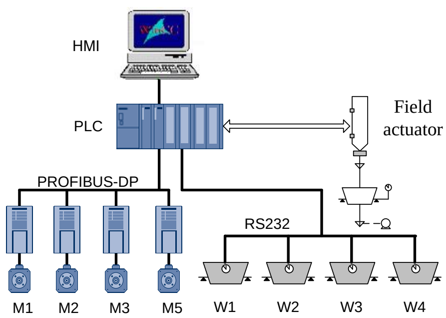

FIGURE 2 Control system hardware structure

To realize the rapid and high-efficiency weighing for the batching process, PLC will send a high-speed signal to the frequency converter when starts the weighing, to drive the vibrating feeder to run at high speed; when the weighing value is close to the target value, PLC will send a low-speed signal to the frequency converter, to drive the vibrating feeder to run at low speed, and; when the weighing value is equivalent to the preact value, PLC will send a stop signal to the frequency converter and inertia before stop will be used to make the weighing value be close to the target value. System control block diagram is shown in Figure 3.

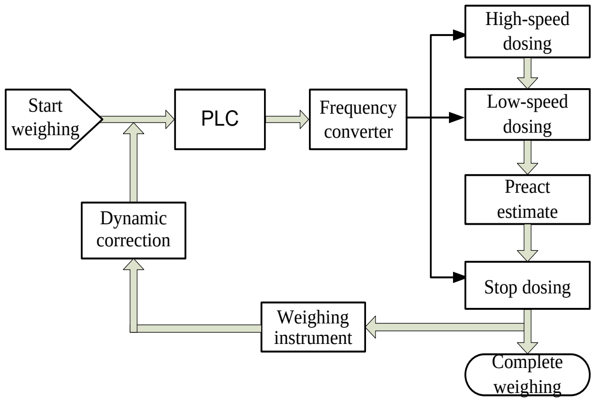

FIGURE 3 System control theory diagram

4 Multi-Level Automatic Batching Control Mode

Time of batch weighing and accuracy of weighing is a contradiction pair [11]. Higher weighing accuracy requires lower speed of dosing, which may lead to the extension of dosing duration. Therefore, that it is to guarantee the accuracy by taking more time, with low production efficiency. However, if the dosing speed is increased, fall of materials in the air can be difficultly controlled within a relatively short duration of weighing and that will easily lead to out-of-tolerance and further affect the weighing accuracy [12].

To realize the rapid and accurate control of the batch weighing process, this system adopts a two-level speed control mode for dosing. High speed (V2) will be adopted for rapid feeding at the beginning of the weighing process [13], and low speed (V1) will be adopted when the materials are close to the target value. Finally, make use of the control mode to calculate the fall in air and the pre-closing time, so as to guarantee the weighing accuracy. The following two factors will affect the performance of weighing for the abovementioned control modes, i.e. changeover between high and low speed and pre-estimate of every fall of dosing [14]. Since material level and shape etc. in the silos are different every time, predicted value of the preact shall be corrected according to the conditions of every dosing and the changeover point for high/ low speed dosing shall be modified as per the conditions such as dosing weight and preact etc.; otherwise cumulative error [15] will appear after several times of weighing. Therefore, the following two dosing control models are designed for control.

4.1 HIGH/ LOW SPEED DOSING CONTROL MODELS

High/ low speed dosing control models are shown in Figure 4 as below. Target of model control is to make sure that the actual weight is between r1 and r2 threshold values for dosing after high/ low speed dosing operation.

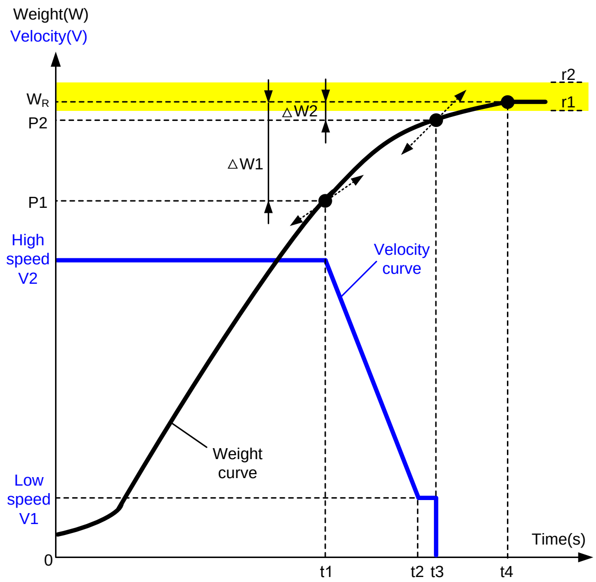

FIGURE 4 High/slow dosing control model

TABLE 1 The four stage parameter of high/low speed dosing control model

Time range	Phase	Weighing value at end point
0-t1	High speed dosing	P_1: weight at high/ low speed changeover point
t1-t2	High/ low speed changeover	
t2-t3	Low speed dosing	P_2: weight at stop point for dosing
t3-t4	Stopping & stabilizing	W_R: stabilized weighing weight

During the dosing process, firstly carry out high-speed vibrating dosing (V_2) before weighing value reaching P_1 and decrease the velocity from V_2 to V_1 by making use of linear method, of which the linear slope will be defined according to time (t2-t1). Then, carry out low-speed vibrating dosing (V_1) and stop dosing when the weighing value reaches P_2. Thereafter, weighing value on the hopper will be stabilized after a certain time due to the fall of dosing. The system will record the dosing stabilization time (t4) and the actual dosing value (W_R), to correct the preact. In addition, to eliminate the cumulative error caused by preact, the system will realize the real-time calculation of the weight difference for high/low speed changeover (preact 1) ΔW_1 and the weight difference between stop dosing – stabilizing (preact 2) ΔW_2 after completing dosing in each silo, including:

Then calculate the next high/ low speed changeover point (P_1) and dosing stop point (P_2) accordingly.

4.2 INCHING DOSING CONTROL MODEL

If high/low speed dosing mode is adopted but the actual weighing value of the silo still cannot reach the target threshold value, inching doing control model will be adopted (as shown in Figure 5).

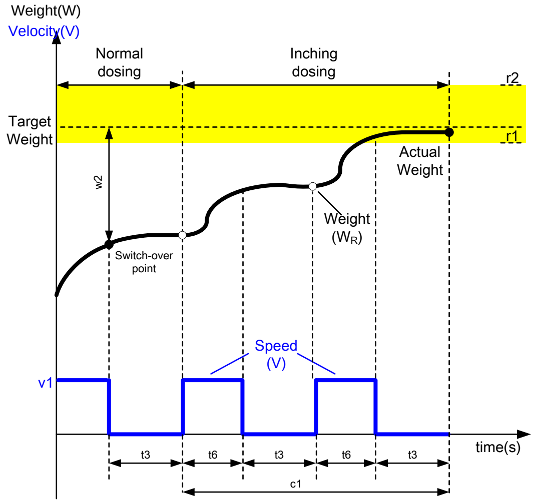

FIGURE 5 Inching dosing control model

Parameters in the figure:

- t6: inching impulse duration;
- t3: inching adjustment duration;
- r1, r2: threshold value for weight target (-)(+);
- w2: weight difference between stop dosing and stabilizing;
- v1: low dosing speed;
- c1: max value of inching dosing number (generally c1=3)

Inching dosing control process includes the following three steps:

1) Start low-speed dosing (v1), time duration t6;
2) Stop low-speed dosing, time duration t3;
3) Calculate the weighing value (W_R); repeat the above inching dosing process if W_R<r1 and the number of inching repeated <= c1.

5 Preact self-adaption correction model

5.1 SELF-ADAPTION CORRECTION OF MODEL

To realize the accurate control of the dosing process and eliminate the cumulative error caused by preact, the system will realize the real-time analysis on the change in deviation during every weighing process and carry out dynamic correction for P1 and P2 after every dosing.

At the time of Nth dosing:

Weighing error:

$$\Delta E(N) = W_R(N) - W_T(N). \quad (1)$$

Target value:

$$W_T(N) = W_P - \Delta E(N-1). \quad (2)$$

Error rate:

$$\Delta U(N-1) = \frac{\Delta W_2(N-1)}{\Delta W_T(N-1)}. \quad (3)$$

Preact 1:

$$\Delta W_1(N) = \Delta W_1(N-1) - \Delta U(N-1). \quad (4)$$

Preact 2:

$$\Delta W_2(N) = \Delta W_2(N-1) - \Delta U(N-1). \quad (5)$$

Formula (3) is the definition of this weighing error; Formula (4) is the definition of this target value; Formulas (5) & (6) are definition of this preact.

If the last error rate ($\Delta U(N-1)$) is much greater, preact set for this time shall be decreased. $P_1(N)$ and $P_2(N)$ shall be calculated as per Formulas (5) and (6).

$$P_1(N) = W_R(N) + \Delta W_1(N), \quad (6)$$

$$P_2(N) = W_R(N) + \Delta W_2(N). \quad (7)$$

The abovementioned method is realized through iteration in PLC and has relatively favourable control effect when the target value is quite great (W_P>30Kg).

If W_P is quite small, $\Delta E(N-1)$ in Formula (1) will be relatively low, error rate $\Delta U(N-1)$ is unobvious, and actual value $W_R(N)$ is quite close to target value $W_T(N)$. However, cumulative error after several times of dosing will have great fluctuation. To make $W_R(N)= W_T(N)$, the following iteration method will be used to carry out dynamic correction for $\Delta W_2(N)$ (correction method of $\Delta W_1(N)$ is similar to this method):

0^{th} time:

$$\Delta W_2(N) = 0. \quad (8)$$

1^{st} time:

$$\begin{aligned} &P_2(1) = W_P - \Delta W_2(0) \\ &\Delta W_2(1) = [\Delta W_2(0) + (W_R(1) - P_2(1))]/2 \end{aligned}. \quad (9)$$

N^{th} time:

$$\begin{aligned} &P_2(N) = W_P - \Delta W_2(N-1) \\ &\Delta W_2(N) = \frac{[\Delta W_2(N-1) + (W_R(N) - P_2(N))]}{2} \end{aligned}, \quad (10)$$

In compliance with the abovementioned iteration method, make use of this preact $\Delta W_2(N)$ to recursively calculate the preact ($\Delta W_2(N+1)$) of next batch after completing every dosing. Accurate estimate of weighing preact can be realized after several batches of dosing weighing, so as to improve the weighing accuracy.

5.2 DESIGN OF SECOND-ORDER ESTIMATOR FOR TARGET VALUE

Controlled object of this dosing control model is meticulous feed batching system, characterized by low silo weighing value, fast dosing and short duration for stop stabilization. To improve the adaptation of model calculation to the meticulous control objects, the system design adopts the following second-order estimator model to predict the actual weighing value ($W_R(N)$):

$$W_R(N+1) = a_1 W_R(N) + a_2 W_R(N-1) + b_0 W_T(N) + b_1 W_T(N-1) + b_2 W_T(N-2), \quad (11)$$

Assign: $\omega(N) = [a_1, a_2, b_1, b_2]$, $X^T(N) = [W_R(N), W_R(N-1), W_T(N-1), W_T(N-2)]$.

Then,

$$W_R(N+1) = b_0 W_T(N) + \omega(N)\cdot X^T. \quad (12)$$

In Formula (12), "$W_R(N+1)$" refers to the $(N+1)^{th}$ actual weighing value; "$W_T(N)$" the set value for the N^{th} weighing; "$\omega(N)$" the parameter vector; and "X^T" the transposition of data vector. Second-order estimator of this system is designed for the purpose of selecting appropriate $W_T(N)$, to minimize the index for the next weighing error.

$$J = [W_R(N+1) - W_P]^2. \quad (13)$$

The following control equation is obtained according to the self-correcting principle:

$$W_T(N) = \frac{W_P - \omega(N)\cdot X^T(N)}{b_0}. \quad (14)$$

Vector $\omega(N)$ shall be recursively estimated by making use of the generalized least squares; and parameter b_0 can be selected at the time of initial calculation. Recursive estimation equation for parameter vector $\omega(N)$ is shown as below:

$$\hat{\omega}(N+1) = \hat{\omega}(N) + K(N+1)\cdot\delta(N), \quad (15)$$

where "$K(N+1)$" refers to the gain matrix and "$\delta(N)$" is the correction term:

$$\delta(N) = [W_R(n+N+1) - X^T(N+1)\hat{\omega}(N)]. \quad (16)$$

Second-order estimation for system design, n=2

Formula (15) defines that: this estimate value of parameter ($\hat{\omega}(N+1)$) is to add a correction term ($\delta(N)$) based on the last estimate value ($\hat{\omega}(N)$). The abovementioned second-order estimator has the following advantages: this estimate value is not only related to the last parameter but also the historical data of the previous $(n+N+1)^{th}$ estimate value and the actual weighing value. Therefore, it reflects the influence of the entire fluctuation process of near-term weighing values on the preact of estimate value. In addition, initial value for recursion should be roughly selected during the recursive process of the generalized least squares, then a brand new group of estimate values will be generated through iterative calculation for ($2n$+1) times, and continue the recursion based on that.

6 Conclusion

This Paper applies the high/ low speed dosing control model to realize the accurate control of batch weighing, i.e. make the material weight be close to the target value as practical as possible during the high-speed dosing process and realize the accurate control of batch weighing during the low-speed dosing process; in addition, adopt the inching dosing method to compensate the weighing accuracy of low-speed dosing. Upon completion of each dosing, carry out dynamic correction for the next preact ($\Delta W_1(N)$ and $\Delta W_2(N)$), and make use of the second-order estimator to predict the target value ($W_T(N)$). This control calculation method has been used in a certain meticulous batch weighing system. Table 2 shows the process data for real-time control (set value for technology 40Kg) of a silo. Before adopting new calculation method, it will take about 5 minutes and 20 seconds for completing one weighing and the accuracy error will reach ±0.12Kg after several continuous weighing. With the increase in weighing times, cumulative error will be greater and greater. After applying the new calculation method, completion of one weighing of three materials will be controlled within 4 minutes and 30 seconds.

TABLE 2 The process data of continuous 20 batches

No	Actual value $W_R(N)$	Dosing stop point $P_2(N)$	Preact $\Delta W_2(N)$	Error $\Delta E(N)$
0	40.0000		0.0000	0.0000
1	38.2520	40.0000	-0.8740	-1.7480
3	40.6780	39.2625	0.3390	-2.5450
5	40.1530	40.6410	0.0765	-1.1100
7	40.5580	40.0420	0.2790	-0.4680
9	39.9250	40.3875	-0.0375	0.2320
11	39.8250	40.0290	-0.0875	0.1150
13	39.8060	39.9980	-0.0970	-0.0830
15	40.0110	40.0020	0.0055	-0.0680
17	40.0650	39.9990	0.0325	-0.0050
19	39.9990	40.0085	-0.0005	0.0110
20	40.0020	39.9995	0.0010	0.0130

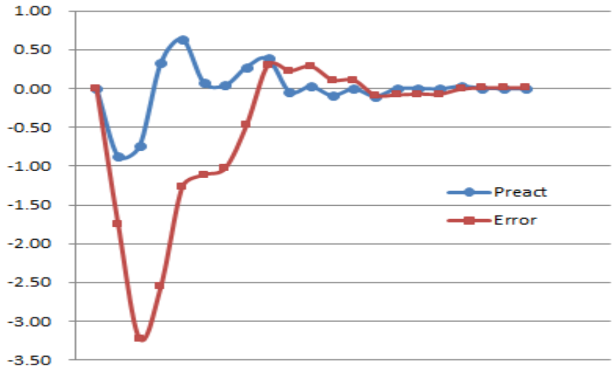

FIGURE 6 the Trend graph of Error and preact of continuous 20 batches

According to the variation trend of error and preact as shown in Figure 6, the weighing accuracy after 20 times of continuous weighing can be controlled approximately ±0.01Kg and the increase in weighing times will not affect the cumulative error and preact. Therefore, the new calculation method can effectively mitigate the contradiction between weighing velocity and accuracy and furthermore fully satisfies the production need of the entire technology. In addition, this control model can, characterized by reasonable design and simple operation, realize the rapid and accurate control of batch weighing process and has quite favourable control and reliability.

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References

[1] Song Yuepeng 2008 Research on Automatic Batching System Based on PLC with Self-Correcting Fuzzy Control *Electrical Drive* **38**(8) 72-4

[2] Song Hui, Fang Zongda 2003 Measures about Weighing of Automatic Batch Control System *Automation and Instrument & Meters* **2** 23-4

[3] Status and Ralph 2002 Improved Temperature Control in Batch Production Systems *ISA TECH/EXPO Technology Update Conference Proceedings* **422** 109-15

[4] Hogenson and David C 1990 Four Approaches to Batch Control *Advances in Instrumentation Proceedings* **45**(1) 133-6

[5] Labs and Wayne 1993 Control Software Features Batch Management and PLC-Based PID *Instruments & Control Systems* **66**(4) 102-11

[6] Jones and Wardin 1991 Design of a PLC Based Control System for a Batch Reactor *Proceedings of the IASTED International Symposium oil Circuits and Systems* 902-11

[7] Skontos and Sam 1991 PLCs Challenge DCSs in Batch Control *Process and Control Engineering* **44**(4) 48-50

[8] Bonnina and Anthony T 1990 Workstations and PLCs for Batch Control *Instruments & Control Systems* **63**(11) 53

[9] Liu Chao, Bai Ling, Liu Feng 2010 Error Compensating Model of Smoothness Self-Adaptation of Feedstuff Mixing and Application *Feed Industry* **31**(21) 1-3

[10] Jeffery R 1998 Integrating Scales and Weight Information and PLCs *Australian Journal of Instrumentation and Control* **13**(3) 10-16

[11] Troys and Dougalas 1996 Development Environment for Batch Process Control *Computers in Industry* **31**(1) 6l-84

[12] Zhang Qingbin Bi Lihong, Wang Zhu 2005 Analysis on Accuracy of Industrial Automatic Batching System *Automation Technology and Application* **24**(5) 79-81

[13] Wishowski and Kirk E 1994 Automated Control of Batch Mix Tank is Wed to Manual Procedures and Operator Intervention *Instrumentation & Control Systems* **67**(7) 59-65

[14] South and Crai 1995 Continual Batch Processing for Liquid Wastes. *Process and Control Engineering* **48**(6) 26-8

[15] Sumi and Takao 1990 Supervisory System for Batch Process *Advances in Instrumentation Proceedings* **45**(3) 1115-22

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