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EWMA Controller with Concurrent Adjustment for a High-Mixed Production Process

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Abstract

The exponentially weighted moving average (EWMA) feedback controller is a very popular run-to-run (RtR) process control scheme in the semiconductor industry. Traditionally, the manufacturing environment was simplified as a single product and single tool process. In the feedback control, the adjustment of the recipe for the next run is related to the deviation of the current output against the desired target. However, in a commercial foundry, every tool always works for many products. It is called a multiple products and single tool (MPST) process. The challenge of this process is how to adjust the recipes among different products in a production row.

In this study, a modified threaded EWMA feedback controller, the EWMA with concurrent adjustment, is proposed to deal with the issue of multiple products in a tool. When the process disturbances follow an IMA(1,1) time series model, the stability of the proposed method will be proven. The optimum discount factors of the proposed EWMA controller will be investigated by several simulations in terms of the number of multiple products, their distribution and the scheduling of the process. Moreover, according to results of the performance comparisons with threaded EWMA, the proposed controller is advantage in the large number of multiple products and in low-frequency products.

Keywords: EWMA, run-to-run, feedback controller, high-mixed production process, concurrent adjustment

1. Introduction

Run-to-Run (R2R) process controller has been a conversional quality control technique in semiconductor manufacturing process. It was purposed by integrating statistical process control (SPC) and engineering process control (EPC) for overcoming the shift or gradually drift in the complex manufacturing process [1-2]. In most semiconductor manufacturing process, the run-to-run process controller for adjusting the input recipe is based on a known prediction model. Assume that the I/O relationship of the SISO process is linear, the process outputs (y_t) can be expressed as follows:

$$y_t = \alpha_0 + \beta_0 x_{t-1} + \epsilon_t \tag{1}$$

where x_{t-1} denotes the process input at run t that has been adjusted after its previous output y_{t-1} obtained, α_0 and β_0 are the intercept and slope parameters, respectively, and ϵ_t denotes the process disturbances. The next process input at run $t+1$ will be adjusted by:

$$x_t = \frac{\tau - a_t}{b} \tag{2}$$

where τ is the process target, b is the estimate of the slope β and a_t is the new estimate of α_0 by using the following EWMA formula:

$$a_t = \omega\left(y_t - bx_{t-1}\right) + \left(1-\omega\right)a_{t-1} \tag{3}$$

Typically, the researches related to the topic of how to enhance the performances of R2R controller are very restricted in a single product and single tool (SPST) production environment. However, in many real commercial production processes, a tool will produce several different products. The same type of products might not be produced in-a-row. The kind of manufacturing

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mode is often called a multiple-product- multiple-tool (MPMT) or a high-mixed production process. The foundries in Taiwan are the typical examples of the high-mixed manufacturing mode. The manufacturing environment consists of multiple products passing through a sequence of batch processing steps being that are out by multiple parallel tools. Recently, R2R control implementation in a MPMT environment has been discussed by many authors [3-5]. Most of these works have attempted to identify parameters that can characterize the product and tool states. However, information is never shared between products or tools in such an approach. Thus, EPC or SPC are ineffective for low frequency products. Lee et al. [6] proposed a cumulative sum-type statistical process control for a MPMT process to detect substantial changes in tool and product effects. The estimate of gain parameter will be updated after signals. The recipes of inactive products will be adjusted if SPC emits a signal. For statistical significance, the signal is related to the number of different products. In this short paper, the EWMA with concurrent adjustment algorithm for a multiple products and single tool (MPST) process is proposed for inactive products. Such that, when those products become active, their corresponding recipes can reflect the effect of the tool change.

The organization of the paper is as follows. The proposed EWMA with concurrent adjustment algorithm is introduced in section 2. In section 3, the stability condition of the proposed method and the evaluation of its performance will be shown. Conclusions were then drawn in section 4.

2. EWMA Controller with Concurrent Adjustment

If we assume the initial estimates of parameters α and β of (1) are correct, the input recipe will be set $\tilde{x} = \frac{\tau-\alpha}{\beta_0}$ for all runs to make the expected output meet the process target. Without loss generality, we can simplify (1) by the following expression:

$$y_t = \beta_0 x_{t-1} + \epsilon_t \tag{4}$$

Assume that there are J products will be produced in a tool. Let $x_{j,t-1}$ and $y_{j,t}$ denote the process input and output at run t. Since a tool just can produce one product at each run, the product index j is a function of t. The product j is active at run t, but other $J-1$ products are inactive. In this paper, the I/O relationship of the MPST environment is

$$y_{j,t} = \beta_j x_{j,t-1} + \epsilon_{j,t} \tag{5}$$

where β_j denotes the slope parameter with respect to product j and $\epsilon_{j,t}$ denotes the process disturbance. Denote $\beta_j = \beta_0 f_J$, where β_0 denotes the nominal tool effect parameter and f_j denotes the nominal product effect for product j about the reference product. Moreover, we take the contrast $f_1 = 1$ for identifiability. Denote $b_{j,0}$ as the initial estimate of $\beta_j, j = 1, \cdots, \mathrm{J}$ then $b_{1,0}$ is also the estimate of β_0 and the estimates of the nominal product effects are $\hat{f}_j = \frac{b_{j,0}}{b_{1,0}}$. Hence, the initial prediction model can be expressed as follows:

$$E\left(y_{j,t} \mid x_{j,t-1}\right) = b_0 \hat{f}_j x_{j,t-1} \tag{6}$$

For the current active product j, its recipe can be adjusted by

$$x_{j,t} = \frac{\tau_t - a_{j,t}}{b_0 \hat{f}_j}, \tag{7}$$

where $a_{j,t} = a_{j,t-1} + \omega\left(y_{j,t} - \tau_t\right)$ is the formal EWMA formula, but for the inactive products $j' \neq j$. We propose the concurrent adjustment

$$a_{j',t} = a_{j',t-1} + \theta c_t \tag{8}$$

where $c_t = \omega\left(y_{j,t} - \tau_t\right)$ and ϑ denotes the concurrent factor.

3. Results and Discussion

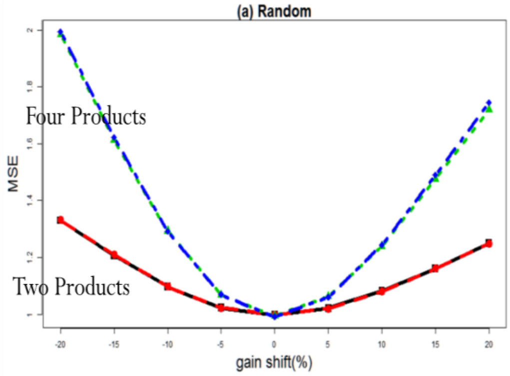
The offset of the process output can be expressed by

$$\begin{aligned} y_{j,t} - \tau_j = {} & \phi^2\left(y_{j,t-h_l^j-h_{l-1}^j-2} - \tau\right) - \phi\frac{\vartheta\beta_{0,j}}{b_{0,j}}C_{j,l-1} \\ & - \frac{\vartheta\beta_{0,j}}{b_{0,j}}C_{j,l} + \left(1-B^{h_l^j}\right)\epsilon_{j,t} \\ & + \phi\left(1-B^{h_l^{j-1}}\right)\epsilon_{j,t-h_l^j-1} \end{aligned} \tag{9}$$

where l denotes the series index of product j,

$\emptyset_j = \left(1 - \frac{\omega\beta_{0,j}}{b_{0,j}}\right)$ denote the stable factors, $C_{j,l} = \sum_{i=t-h_l^j}^{t-1} c_i$ denotes the cumulative deviation from target and B denotes the backward operator. When the process disturbances is an IMA (1, 1), or a ARMA (p, q), the variance of the process output is bounded if $|\emptyset_j|$ is smaller than 1 for all j. According to several simulations in different conditions of the production environment, $\omega = 0.2$ and $\vartheta = 1.0$ are suggested. The performance of the proposed method was evaluated based on the criteria of the relative efficiency, the ratio of mean square errors of the proposed method to that of the threaded EWMA controller under the same conditions. Fig. 1 shows the results of the relative efficiency comparisons No matter what product scheduling (random or concentration) is, what the number of product types (2 or 4) is and what the magnitude of slope shift is, Fig. 1 explicitly shows the proposed method is better than the threaded EWMA controller.

(a) Random



(b) Concentration

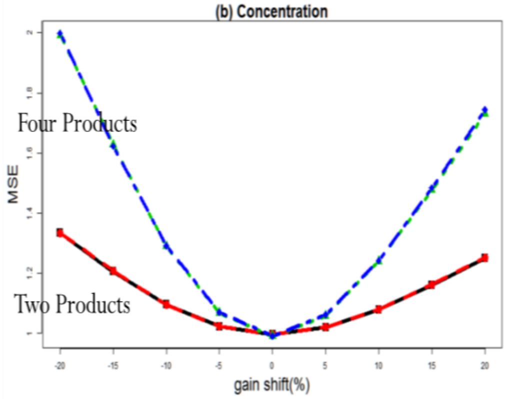


Fig. 1 The relative efficiency of the EWMA controller with concurrent adjustment with respect to the threaded EWMA controller

4. Conclusions

In this paper, the EWMA with concurrent adjustment algorithm control was proposed for a multiple products process. The exact expression of the process output of the proposed control algorithm is derived. Hence, its stability conditions can be obtained. Based on several numerical simulations, $\omega = 0.2$ and $\vartheta = 1.0$ are suggested for the discount factor of EWMA controller and concurrent factor when the process disturbances are a white noise series. Compare to the threaded EWMA controller in different production scheduling, the advantage of the EWMA with concurrent adjustment is increasing in terms of the magnitude of the slope shift. Moreover, the larger the number of product types, the bigger the advantage.

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