Journal of Graphic Era University
Vol. 5, Issue 2, 147-154, 2017
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Control System Design with Dead Time Compensation for a Multivariable Lime Kiln Process

Sandeep Kumar Sunori[1], Pradeep Kumar Juneja[2], Mayank Chaturvedi[3*]

[1,2]Department of Electronics and Communication Engineering
[3]Department of Electrical Engineering
[1]Graphic Era Hill University, Bhimtal Campus
[2,3]Graphic Era University, Dehradun, India
[*]Corresponding author: mayankchaturvedi.geit@gmail.com

(Received November 15, 2016; Accepted December 27, 2016)

Abstract
Lime kiln is used in numerous process industries such as, paper mill, sugar mill, cement mill etc. The limekiln is fundamentally challenging to operate proficiently due to intricate structure with non-linear reaction kinetics, and large dead time. It turns out to be dangerous if it is functioned outside the set points. So, the automation of this process is very critical for optimization of product quality, product rate and economy. The current research work deals with a 2x2 lime kiln model. Having done its multivariable analysis, its decoupling has been done. Using MATLAB, dead time compensation is done with smith predictor design and its performance is compared to that of control system without dead time compensation.

Keywords- Lime Kiln, Dead Time, Multivariable, Smith Predictor, Set-Point Tracking.

1. Introduction
Limekiln is basically cylindrical in shape which rotates. It has got certain inclination to the ground as depicted in Figure 1 (Naud and Emond, 2007). It essentially converts calcium carbonate (mud of lime) into calcium oxide (lime) by the process which is termed as calcination. This transformation procedure has an endothermic nature i.e. a supply of huge heat content is essential to furnish this process.

The whole lime kiln may be viewed as 3 temperature regions viz. the drying region at a temperature of two hundred thirty Fahrenheit, heating region at a temperature of six hundred Fahrenheit and the calcination region at a temperature of fifteen hundred Fahrenheit. The measure of the lime quality is the amount of residual carbon dioxide in the resulting CaO (Sunori et al., 2015). A 2 level controller for tunnel kiln was reported where the model predictive control and fuzzy logic techniques were exploited (Stojanovski and Stankovski, 2011). Zhu and Zhang (2014) presented the knowledge base designing for an expert system for rotary lime kiln. Bharadwaja (2014) made use of PLCs for lime kiln process.

Journal of Graphic Era University
Vol. 5, Issue 2, 147-154, 2017
ISSN: 0975-1416 (Print), 2456-4281 (Online)

2. Multivariable Analysis of the Plant Model

The Fuel Rate (FR) and the opening of ID fan (v_p) are the two input variables while the front end temperature (T_{fe}) and back end temperature (T_{be}) are the output controlled variables for the considered model. The equation (1) presents the considered transfer function model which has been borrowed from the work done by (Juneja et al., 2013) on the same process using MPC technique.

$$\begin{bmatrix} T_{fe} \\ T_{be} \end{bmatrix} = \begin{bmatrix} \dfrac{12.8e^{-s}}{16.7s+1} & \dfrac{-18.9e^{-3s}}{21s+1} \\ \dfrac{6.6e^{-7s}}{10.9s+1} & \dfrac{-19.4e^{-9s}}{14.4s+1} \end{bmatrix} \begin{bmatrix} F \\ vp \end{bmatrix} \tag{1}$$

The Figure 2 displays the open loop plots namely step response, Nyquist plot, Bode magnitude plot and pole- zero plot of the considered 2x2 plant. These plots clearly indicate that the plant model is physically realizable and BIBO (bounded input-bounded output) stable. Now, for designing the controller, let's determine the suitable input-output control loop pairing by investigating the relative gain array (RGA).

$$RGA = K * (K^T)^{-1} \tag{2}$$

Here K is the steady state gain matrix.

Let

$$RGA = \begin{bmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \end{bmatrix} \tag{3}$$

If $\lambda_{12} < \lambda_{11}$ then suitable pairing is u_1-y_1 and u_2-y_2 else, it is u_1-y_2 and u_2-y_1.
For the taken up model,

$$[K] = \begin{bmatrix} 12.8 & -18.9 \\ 6.6 & -19.4 \end{bmatrix} \tag{4}$$

Using equations (2) and (4), the RGA for this plant comes out as,

$$RGA = \begin{bmatrix} 2.0094 & -1.0094 \\ -1.0094 & 2.0094 \end{bmatrix} \tag{5}$$

The pairing u_1-$y_1$and u_2-y_2 is suggested by this RGA. The other factor to be investigated is the Niederlinski index (Niederlinski, 1971). If its value comes out to be negative, then it would be impossible to control both output variables at the same time.

Journal of Graphic Era University
Vol. 5, Issue 2, 147-154, 2017
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Mathematically,

$$NI = \frac{Det[K]}{K_{11}K_{22}} \tag{6}$$

Now using equation (6) on the considered plant model.

$$NI = \frac{\begin{vmatrix} 12.8 - 18.9 \\ 6.6 \ -19.4 \end{vmatrix}}{12.8X(-19.4)} = 0.497 \tag{7}$$

Which ensures the controllability of both output variables at the same time.

3. Decoupler Design

Figure 3 (Ogunnaike and Ray, 1994) presents the block diagram with of a control system with de couplers. Following two outputs are generated by it,

$$y_{1(s)} = \left[g_{11}(s) - \frac{g_{12}(s)g_{21}(s)}{g_{22}(s)} \right] v_1(s) \tag{8}$$

$$y_{2(s)=}\left[g_{22}(s) - \frac{g_{12}(s)g_{21}(s)}{g_{11}(s)} \right] v_2(s) \tag{9}$$

The two decoupled systems obtained using equations (8) and (9) are represented by equations (10) and (11) respectively.

$$G_1(s)\frac{(2.684*10^4 s^2 + 4042s + 123.6)e^{-s}}{7.416*10^4 s^3 + 1.478\times10^4 s^2 + 942.8s + 19.4} \tag{10}$$

$$G_2(s) = \frac{(-2.684\times10^4 s^2 - 4042s - 123.6)e^{-9s}}{4.219\times10^4 s^3 + 8810s^2 + 592.6s + 12.8} \tag{11}$$

4. Dead Time Compensation

The Smith predictor is deployed in the control system for nullifying the unwanted impacts of the dead time. This strategy can be implemented only for constant time delays. The Figure 4 shows the block diagram of Smith Predictor with the plant G(s), controller C(s), internal model $G^{'}(s)$(G(s) without dead time θ). Here, SP, θ and d, are representing the set- point, time delay and the output disturbance respectively (Smith, 1957; Smith, 1959).

Journal of Graphic Era University
Vol. 5, Issue 2, 147-154, 2017
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Now, for the decoupled model $G_1(s)$, the tuned controller $C_1(s)$ is presented in equation (12).

$$C_1(s) = 0.238\left(1 + \frac{1}{18.03s}\right) \tag{12}$$

Similarly, for the process $G_2(s)$, the tuned PI controller $C_2(s)$ is presented in equation (13).

$$C_2(s) = -0.13\left(1 + \frac{1}{15.49s}\right) \tag{13}$$

The first order filter F(s) is expressed in equation (14).

$$F(s) = \frac{1}{(10s + 1)} \tag{14}$$

The servo and the disturbance rejection performance of the control system for system $G_1(s)$, with and without smith predictor is show cased in Figure 5. The respective parameters are presented in Table 1, indicating that the performance is greatly improved. Similarly Figure 6 presents the servo and the disturbance rejection performance of the control system with and without smith predictor, for the system $G_2(s)$.

The corresponding performance parameters are mentioned in Table 2, showing control system performance is appreciably improved here also. Figures 7 and Figure 8 show the Bode plots of the control systems with and without Smith predictor for $G_1(s)$ and $G_2(s)$ respectively showing bandwidth improvement by the Smith predictor.

5. Conclusion

In the present research work, a 2x2 lime kiln industrial process with some time delay is considered, and the control system performance with and without Smith predictor has been investigated for it using MATLAB. It is observed that the adverse effects of time delay are greatly cancelled by dead time compensation using a Smith predictor in the control system. The control system with Smith predictor comes up with less settling and rise time, and quicker disturbance rejection. It also enhances the bandwidth of the control system.

Journal of Graphic Era University
Vol. 5, Issue 2, 147-154, 2017
ISSN: 0975-1416 (Print), 2456-4281 (Online)

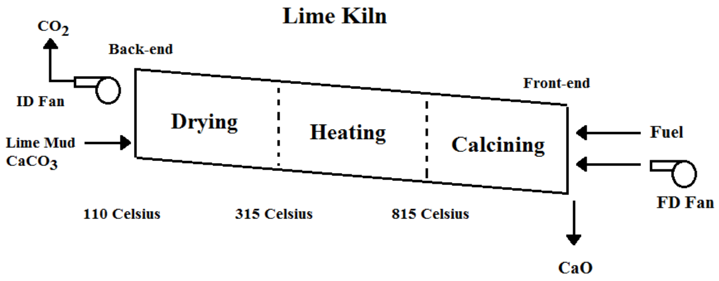

Figure 1. Lime kiln process

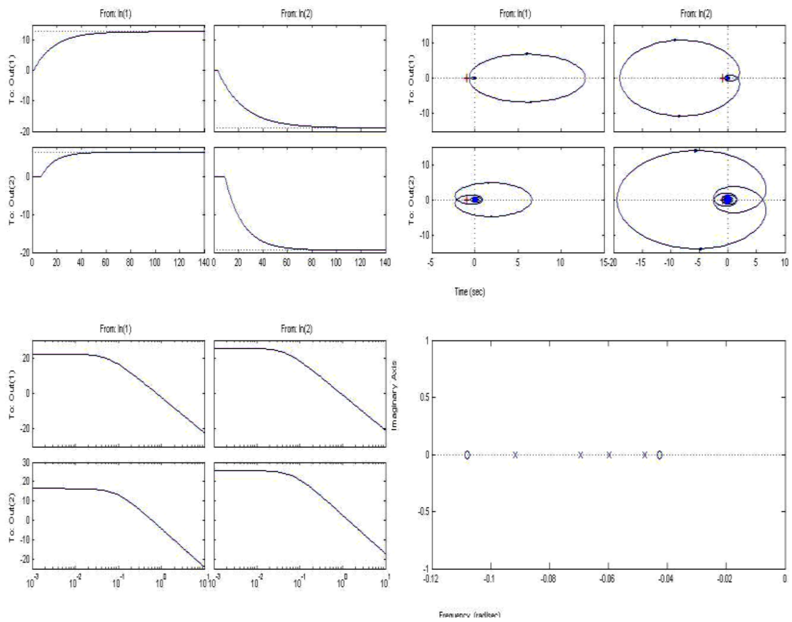

Figure 2. Step response (top left), Nyquist plot (top right), Bode magnitude plot (bottom left), Pole-zero Plot (bottom right)

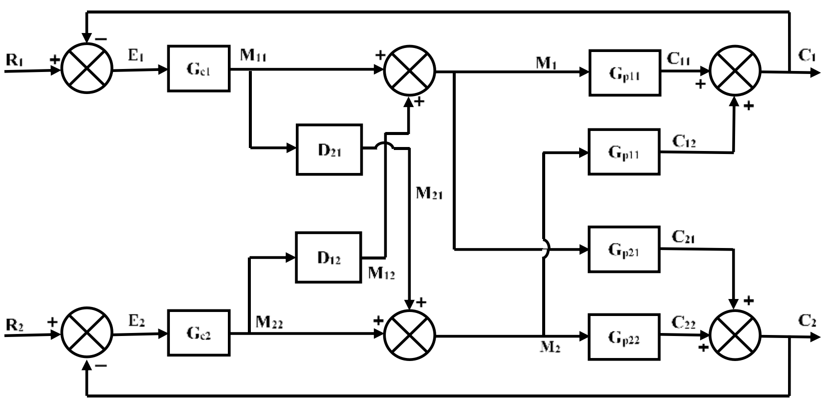

Figure 3. Control system with de couplers

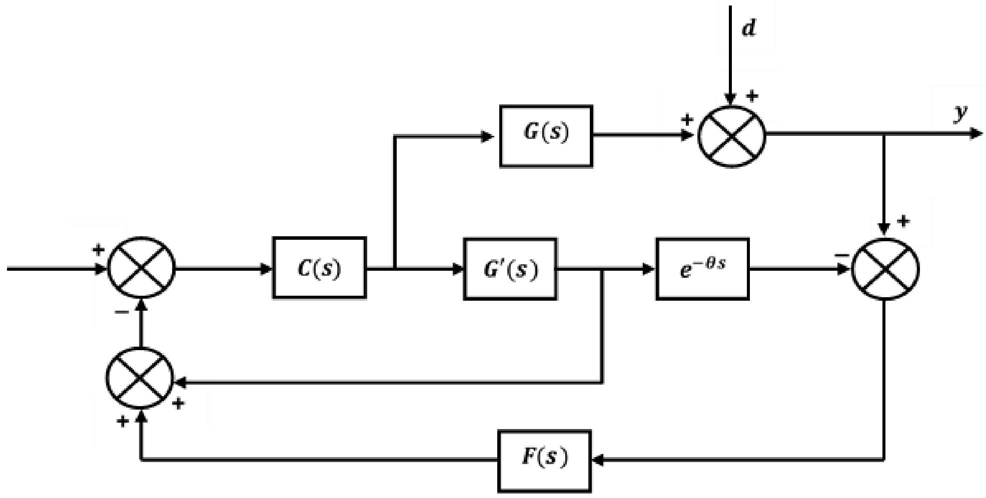

Figure 4. Control system with Smith predictor

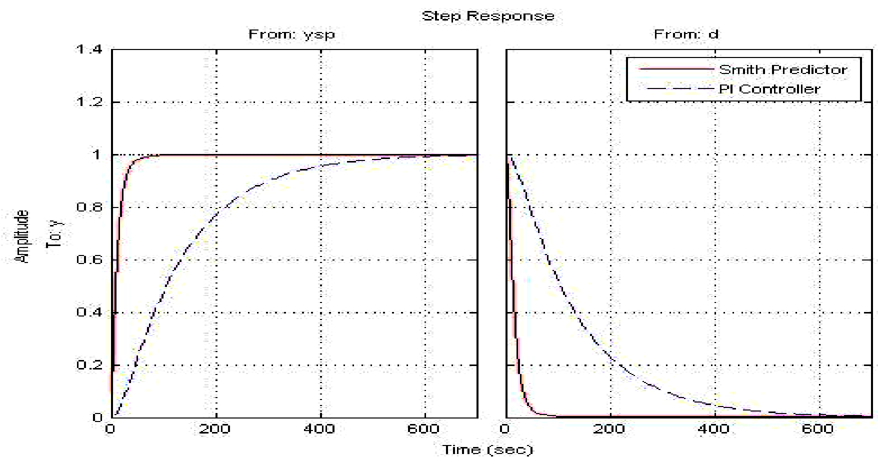

Figure 5. Control system performance for $G_1(s)$

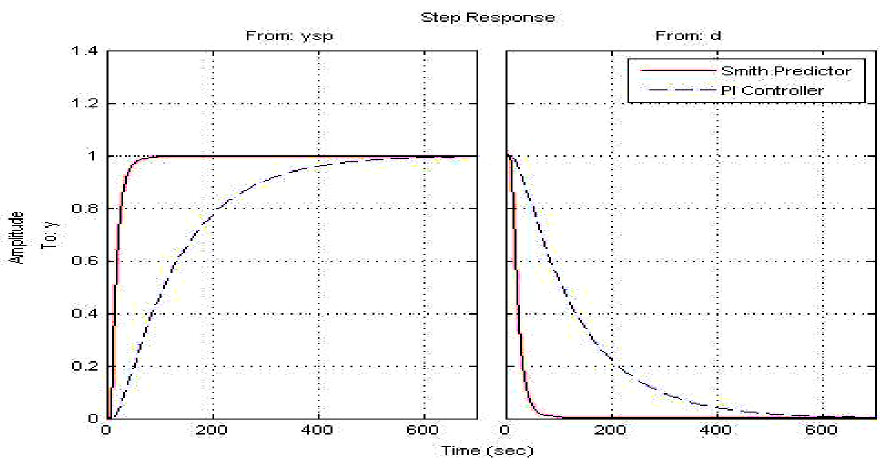

Figure 6. Control system performance for $G_2(s)$

Journal of Graphic Era University
Vol. 5, Issue 2, 147-154, 2017
ISSN: 0975-1416 (Print), 2456-4281 (Online)

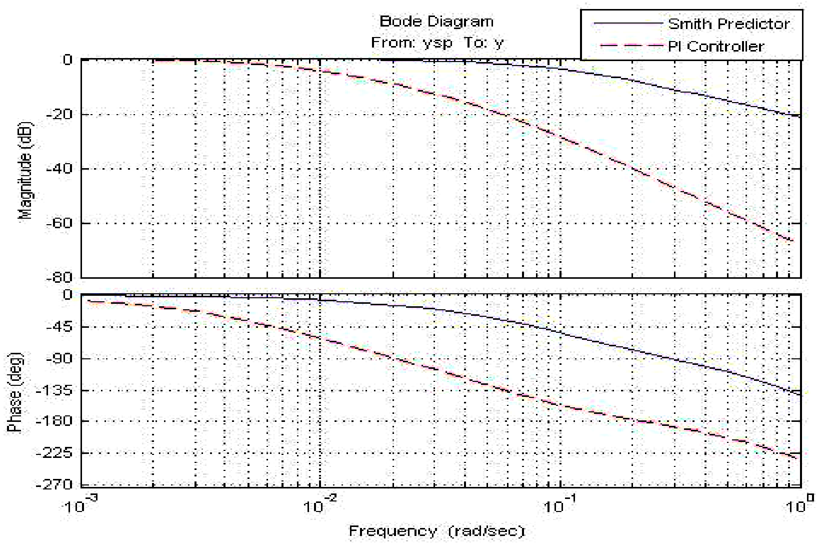

Figure 7. Bode plots of control system for $G_1(s)$

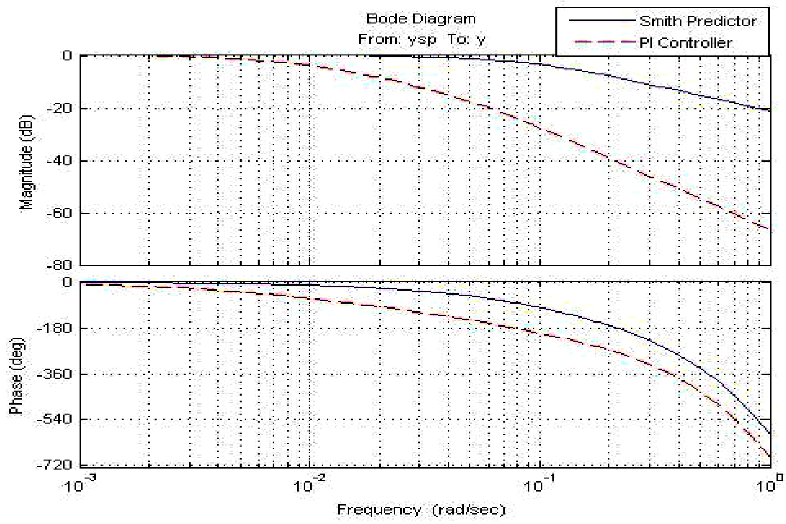

Figure 8. Bode plots of control system for $G_2(s)$

Parameter	PI Controller	Smith Predictor
Settling time(sec.)	502	52.5
Rise time (sec.)	274	25.1
Disturbance –Rejection time(sec.)	600	100

Table 1. Comparison of performance parameters for $G_1(s)$

Parameter	PI Controller	Smith Predictor
Settling time(sec.)	483	59.4
Rise time (sec.)	290	25
Disturbance –Rejection time (sec.)	600	100

Table 2. Comparison of performance parameters for $G_2(s)$

References

Bharadwaja, Y. (2014). Intelligent control system of lime kiln process by programmable logic controllers. Journal of International Academic Research for Multidisciplinary, 2(5), 457-461.

Juneja, P. K., Ray, A. K., & Mitra, R. (2013). MPC based controller design for a constrained industrial lime kiln process. Journal of Forest Products and Industries, 2(6), 7-9.

Naud, S., & Emond, M. (2007). Lime kiln control using simple advanced regulatory control strategy, ISA EXPO 2007, Reliant Center, Houston, Texas, 1-4.

Niederlinski, A. (1971). A heuristic approach to the design of linear multivariable interacting control systems. Automatica, 7(6), 691-701.

Ogunnaike, B. A., & Harmon Ray, W. (1994). Process dynamics, modeling and control, Oxford University Press.

Smith, O. J. M. (1957). Close control of loops with dead time. Chemical. Engineering. Progress. 53(5), 217-219.

Smith, O. J. M. (1959). A controller to overcome dead time. ISA Journal, 6(2), 28-33.

Stojanovski, G., & Stankovski, M. (2011). Advanced industrial control using fuzzy-model predictive control on a tunnel klin brick production. IFAC Proceedings Volumes, 44(1), 10733-10738.

Sunori, S. K., Verma, D., Shree, S., & Juneja, P. K. (2015). Neuro-fuzzy controller design for lime kiln process. In 2015 2nd International Conference on Recent Advances in Engineering and Computational Sciences (RAECS), 1-6, IEEE.

Zhu, L., & Zhang, T. (2014). Implement and research on the expression methods of knowledge for the expert system of rotary kiln. Sensors and Transducers, 162 (1), 280-285.