A robust adaptive method to control the crushing mill machine

Conference Paper · December 2011

DOI: 10.1109/ICCIAutom.2011.6356717

Hamid Behzad
Shahrood University of Technology

Saeed Khorashadizadeh
University of Birjand

Ali Akbarzadeh Kalat
Shahrood University of Technology

A Robust Adaptive Method to Control the Crushing Mill Machine

Hamid Behzad, Saeed Khorashadizadeh, and Ali Akbarzadeh Kalat

Abstract— This paper is concerned with the adaptive control of sugar mill system and develops a controller based on indirect self tuning regulators in which the system parameters are identified using recursive least squares (RLS) method and the controller is designed using pole placement approach. The Sugar mill system is a linear multivariable system. Thus, designing a controller to overcome couplings and uncertainties such as external disturbances and parametric uncertainties is a critical problem. The most important novelty of this paper is using the disturbance rejection ability of self tuning regulators to overcome the coupling problem, since couplings are considered as disturbances in this paper. Simulation results are presented to verify the efficiency of the designed indirect self tuning regulator in the control of crushing mill machine. Moreover, the performance of the designed STR is compared with a sliding mode controller.

I. INTRODUCTION

TO historically mark the advent of sugar making industry using sugar cane has been always a matter of great debate. While several approaches are introduced for extraction of sugar cane syrup, using mill is nowadays more prevalent in several factories. Each mill consists of three rollers two of which are fixed while the upper one hydraulically adjusts the pressure in proportion to the input feed.

Since canes with different dry matter qualities are fed into the system, achieving maximum extraction requires the pressure of the mills, torque of the rollers and height of the input feet to be controlled and maintained [1,2].

The torque control has significant influence on juice extraction [3] and the height of the material in the buffer chute should be at a level to achieve an adequate degree of compression of the material for efficient smashing [4]. It is noteworthy that the chute height and the roll torque are closely coupled. Here, the height control is achieved by changing the turbine speed and the torque control is maintained by geometrical changing of the chute via the flap [4]. Considering the interdependence of height and torque, on the one hand, and the differences in dry matter qualities fed, on the other, to design a controller that acts as decouple and is robust to dry matter of different qualities is of great significance.

PID controllers are well adjusted for the sugar mill control. But they are not robust enough against changes in raw materials [5]. So, adaptive and robust controllers are the best choice. Robust controller was implemented by Partanen et al in 1994. Although these controllers are robust against changes in the model of the system, adaptive controllers solve the control problem for a larger uncertainty set than a robust controller. Moreover, the degree of the controller is very high compare to the process model [6].

Sliding mode control as an efficient robust control strategy has attracted considerable research interests and many complicated systems such as robot manipulators [7], cooperative autonomous mobile robots [8], electro-hydraulic systems [9] and variable speed wind energy conversion systems [10] have been successfully controlled using sliding mode control. This robust control method has been applied to the crushing mill machine [3] and we will compare the performance of this controller with the proposed controller in this paper.

Adaptive controllers are preferred, since their ability to on-line identification of the process model and consequently, wide ranges of uncertainty have been included and they do not require high order controllers. These controllers not only have strong mathematical foundation but also defined in terms of sustainability [6]. Self tuning regulator (STR) and model reference adaptive systems (MRAS) are two adaptive control methods both of which have more applications methods than others. Self tuning regulators are very popular and have been applied to control many important systems [11-15].

In this paper, due to changes of process model and non-minimum phase property of it, STR is the chosen method. There are different kind of STR controllers among which pole placement method was selected because of its ability in control of non-minimum phase systems and its MIMO decoupling property. Pole placement method is based on designing STR parameters to reach desired close loop poles [16]. Experimental results represent that appropriate selection of designing parameters are vital for success of STR controllers [16].

This paper is organized as follows. Section 2 presents the linear model of the crushing station. Section 3 explains the indirect STR designing procedure. Section 4 presents the simulation results based on STR designing and compares the performance of this control strategy with a sliding mode control design.

H. B. is with the Electrical Engineering Department, Shahrood University of Technology, Shahrood, Iran (corresponding author to provide phone: +989151232040; e-mail: hamidbehzad@ gmail.com).

S. Kh. is with the Electrical Engineering Department, Shahrood University of Technology, Shahrood, Iran (e-mail: s_khorashadi@yahoo.com).

A. A. K., is with the Electrical Engineering Department, Shahrood University of Technology, Shahrood, Iran. (e-mail: aliakkalat@yahoo.com).

II. Modeling

A schematic diagram of a crushing station is shown in Fig. 1. In order to achieve the maximal juice extraction, the buffer chute height and the mill torque should be controlled using the position of the flap mechanism and turbine speed. The following linear model for this system has been obtained using experimental results [3].

$$\begin{bmatrix} \tau(t) \\ h(t) \end{bmatrix} = \begin{bmatrix} \dfrac{-5}{25s+1} & \dfrac{s^2-0.005s-0.005}{s(s+1)} \\ \dfrac{1}{25s+1} & \dfrac{-0.0023}{s} \end{bmatrix} \begin{bmatrix} f(t) \\ \Omega(t) \end{bmatrix} + \begin{bmatrix} \dfrac{-0.005}{s} \\ \dfrac{0.0023}{s} \end{bmatrix} d(t) \qquad (1)$$

where $f(t)$ represents the position of a flap mechanism, $\Omega(t)$ turbine speed, $\tau(t)$ the mill torque, $h(t)$ the buffer chute height, the Furthermore and $d(t)$ the external disturbance.

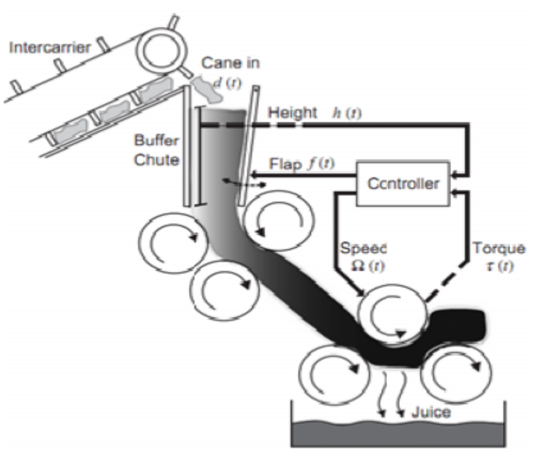

Fig. 1. A crushing station of sugar cane

III. A Pole Assignment Design for the Self-Tuning Regulator Adaptive Controller

We can simplify (1) as

$$\begin{bmatrix} \tau(t) \\ h(t) \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \begin{bmatrix} f(t) \\ \Omega(t) \end{bmatrix} + \begin{bmatrix} D_1(s) \\ D_2(s) \end{bmatrix} d(t) \qquad (2)$$

To simply design the controller, the model is considered as two decoupled single-input/single-output systems $G_{11}(s)$ and $G_{22}(s)$ while the interaction factors $G_{12}(s)$ and $G_{21}(s)$ are considered as disturbance for $G_{11}(s)$ and $G_{22}(s)$, respectively. In order to make practical realization of the controller easier, this paper uses digital control. Since practical implementation of most control systems requires computers or microprocessors and they need digital signals.

Using the sampling time of $t_s = 0.5s$, the discrete time model of the system will become

$$\begin{bmatrix} \tau(q) \\ h(q) \end{bmatrix} = \begin{bmatrix} \dfrac{-0.0099}{q-0.9802} & \dfrac{q^2-2q+1}{q^2-1.607q+0.6065} \\ \dfrac{0.0198}{q-0.9802} & \dfrac{-0.00115}{q-1} \end{bmatrix} \begin{bmatrix} f(q) \\ \Omega(q) \end{bmatrix} + \begin{bmatrix} \dfrac{-0.0025}{q-1} \\ \dfrac{0.00115}{q-1} \end{bmatrix} d(q) \qquad (3)$$

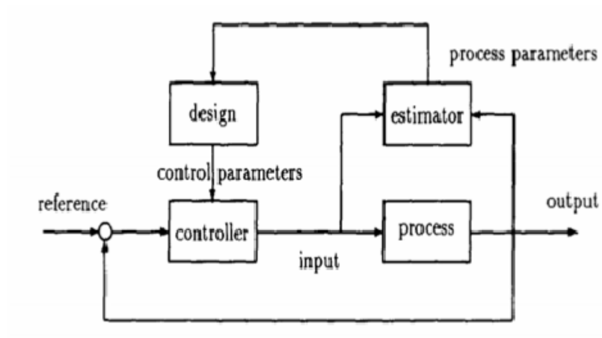

Fig. 2. Block diagram of self-tuning regulator

Indirect self-tuning regulators consist of an identifier and a controller as illustrated in Fig. 2. The identifier which is usually a recursive least squares estimator, uses the process input and output in order to provide an estimate of the process parameters. These estimated parameters will determine the controller coefficients.

The design algorithm is as follows:

1. *Designing an adaptive controller for $G_{11}(s)$ and $G_{22}(s)$, separately.*
2. *Considering $G_{12}(s)$ and $G_{21}(s)$ as disturbance for $G_{11}(s)$ and $G_{22}(s)$, respectively and modifying the controller.*

We can describe $G_{11}(s)$ as

$$A(q)y(k) = B(q)(u(k)+v(k)) \qquad (4)$$

where $y(k)$, $u(k)$ and $v(k)$ denote the digital signals of output, input and disturbance respectively. Furthermore, we assume that $A(q)$ and $B(q)$ are co-prime to each other and that means they do not have common factor. A linear controllers is of the general form:

$$R(q)u(k) = T(q)u_c(k) - S(q)y(k) \qquad (5)$$

in which R, S and T are polynomials and u_c is the command signal. For simplicity, we ignore the argument q of polynomials. Substitution of $u(k)$ from (4) into (5) yields the following closed loop equation:

$$y = \frac{BT}{AR+BS}u_c + \frac{BR}{AR+BS}v \qquad (6)$$

Consider the transfer function

$$G_m(q) = \frac{Y(q)}{U_c(q)} = \frac{B_m(q)}{A_m(q)} = \frac{b_{m0}}{q+a_{m1}} = \frac{0.0351}{q-0.9649} \qquad (7)$$

as the desired closed loop system. According to [17], R and S are calculated by solving Diophantine equation:

$$AR + BS = A_m A_o \qquad (8)$$

where A_o is the observer polynomial. According to compatibility condition

$$A_o = 1 \qquad (9)$$

Due to the causality condition [17], we obtain:

$$deg(T) = deg(R) = deg(S) = 0 \qquad (10)$$

Thus, the polynomials T, R and S are constant values of t_0, r_0 and s_0. Substituting T, R and S in Diophantine equation and equating coefficients of equal power of q yields: $r_0 = t_0 = 1$ and $s_0 = -1.5452$.

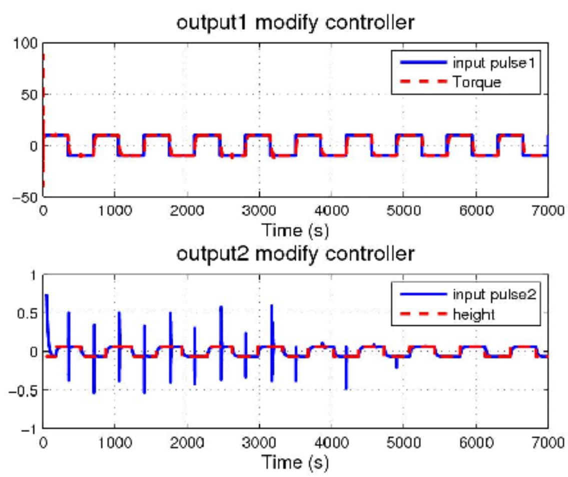

Fig.3. comparing the output and the input pulse after modifying controller

Now, we consider the disturbance to determine the final control signal for the first input. The command signal u_{c2} which passes through $G_{12}(q)$, comes to $G_{11}(q)$ as a disturbance. Therefore, the input disturbance to $G_{11}(q)$ has a determinate dynamic A_{d1} which is related to step disturbance and the dynamic A_{d2} which is related to $G_{12}(q)$.

$$A_{d1} = q - 1 \qquad (11)$$

$$A_{d2} = \frac{q^2 - 1.607q + 0.6065}{q^2 - 2q + 1} \qquad (12)$$

In order to have a limited output in the presence of disturbance, A_{d1} should be a factor of R:

$$R = A_{d1}R' \qquad (13)$$

Now, according to the fact that designed controller has a determinate R^0 and S^0, the new T, R and S are calculated as:

$$R = XR^0 + YB \qquad (14)$$

$$S = XS^0 - YB \qquad (15)$$

in which R^0, S^0 and B are known and we are going to find X and Y. Assume that X and Y are:

$$X = (q + X_0)(q + X_1) \qquad (16)$$

$$Y = (q + y_0) \qquad (17)$$

Using (13)-(17), y_0 will be calculated as

$$y_0 = -\frac{(1+X_0)(1+X_1)r_0}{b_0} - 1 \qquad (18)$$

Substitution of y_0 in (14) and regarding to the fact that X_0 and X_1 are tuning parameters, R and S are calculated using (14) and (15). Finally, replacing R and S from (14) and (15) into (5) yields the control signal for the first channel. Similarly, another controller can be calculated for

$$G_{22}(q) = \frac{b_0}{q+a_1} = \frac{-0.00115}{q-1} \qquad (19)$$

regarding the fact that $G_{21}(q)$ is disturbance function and

$$G_{m22}(q) = \frac{b_{m0}}{q+a_{m1}} = \frac{0.0247}{q-0.9753} \qquad (20)$$

is the desired model.

IV. Simulations and Comparisons

The simulation results are depicted in the following figures. The outputs and the input pulses after modifying controllers are presented in Fig. 3. It is clear that for the first output, after a period of time, the effect of disturbance, which is due to interaction, is omitted. In the second output, which is not an important output, this effect is a notable in the early periods, but is omitted too.

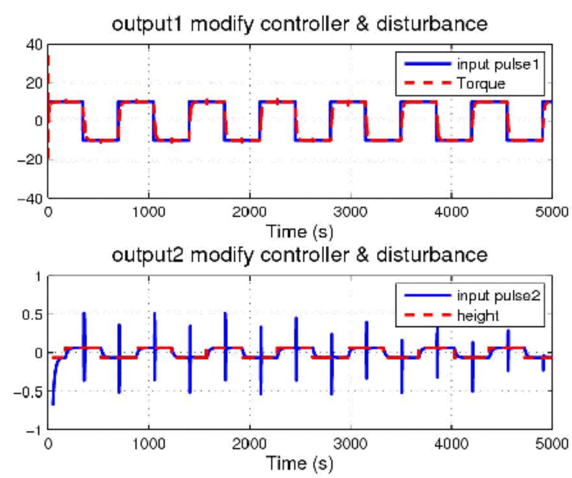

Fig.4. comparing the output and the input pulse after modifying controller and disturbance

Now, for investigating the robustness of our design, we *apply the disturbance which is generated by the fluctuating feed of sugar cane to the buffer chute. This disturbance has a amplitude which is about the domain of the inputs. As it reveals in Fig. 4, it affects just the less important output $h(t)$. It is clear that $\tau(t)$ does not have any changes.*

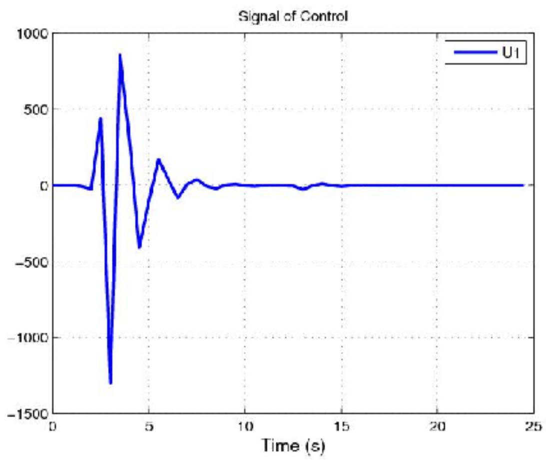

Fig.5. controlling signals for the first input

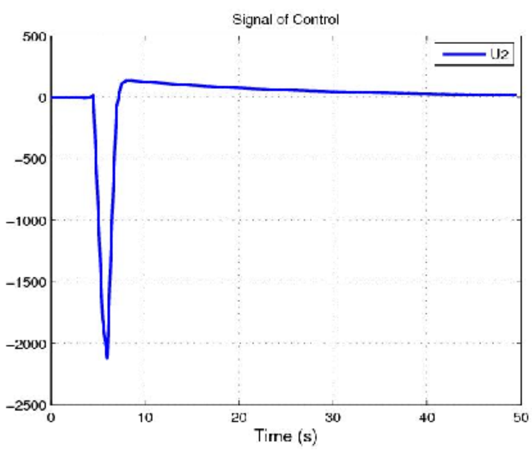

Fig.6. controlling signals for the second input

Fig. 5 and Fig. 6 depict the control signals for the first and second inputs. As it was expected, these signals have high amounts in the first periods, but they limited to a certain amount.

As Fig. 7 reveals, the estimated parameters are convergent to a certain amount after a period of time.

Furthermore, the error signals are depicted in Fig. 8.

As compared with the controller designed in [3], the strategy adopted in this paper is superior. Since the STR is designed in the presence of uncertainty and it assumes that the exact model is not available, while the controller designed in [3] needs the exact model. Moreover, the STR design is simpler.

V. CONCLUSION

An adaptive method was presented to control the torque and the height in the sugar mill. We assume that the model is decoupled, so an adaptive-STR controller was designed and to investigate the robustness, the effect of the disturbance was shown. The method is applicable to a wide variety of systems. As a consequence of the STR controllers, interaction factors are effectively avoided without affecting the decoupling of the system.

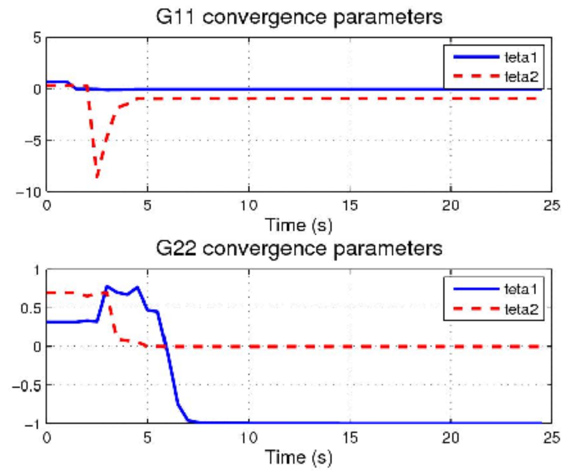

Fig.7. estimated parameters

Some remarkable features of the research are that firstly, we are not concerned about non-minimum phase effect of the right zero. Secondly, STR will decouple the system inherently. Thirdly, the control signal will remain limited after a period of time. Problems for further research include limiting the amplitude of the control signal in the early periods and finding a way to estimate the initial value of the parameters of the model to reach the optimal response.

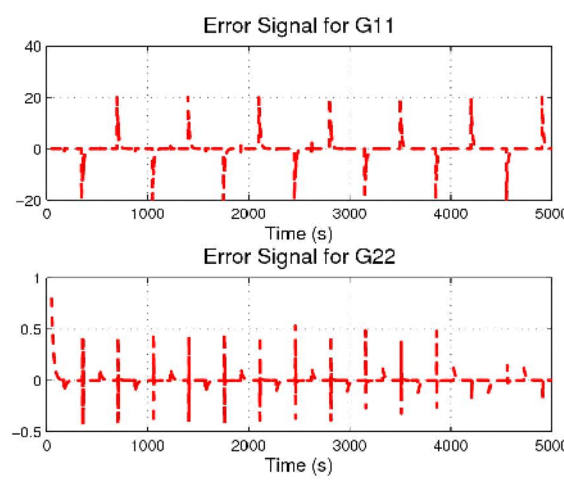

Fig.8. Error Signal

REFERENCES

[1] F.schneider, "technologie des Zuckars," Schaper hannover publication, 1968, pp.521_587

[2] P. W. Van der. Poel, H. Schiwek, T.Schwarz, "Sugar Technology Beet and cane Manufactures," 1998, Ch.6, pp.260_280

[3] Verlag Dr. A. Bartens, Berlin.F. Garelli, R. J. Mantz, H. Battista, “Sliding mode compensation to preserve dynamic decoupling of stable systems” science direct, 2007, pp. 4705_4716.

[4] T.Ozakak, M.Fu, G.C.Goodwin, “A nonlinear modeling approach to sugar cane crushing process” Proceedings of the 37th IEEE Conference on Decision and Control, Florida, 1998, pp. 3144–3149.

[5] A.G.Partanen, R.D.Pierce, R.R.Bitmead, ”Crushing mill control for sugar cane - a robust nonadaptive LQG/LTR strategy” vol2, pregamon press Ltd, 1994, pp. 3_16.

[6] P.Gutman, “Robust and adaptive control: fidelity or an open relationship?”, science direct, volume 49, 2003, pp.9_19.

[7] C. Su, Y. Stepanenko “Adaptive sliding mode control of robot manipulators: General sliding manifold case,” Automatica, Vol. 30, no. 9, pp.1497-1500, Sep. 1994.

[8] M. Defoort, T. Floquet, A. Kokosy, W. Perruquetti, “Sliding mode formation control for cooperative autonomous mobile robots,” IEEE Trans. Industrial Electronics, Vol. 55, no. 11, pp. 3944-3953, Nov. 2008.

[9] C. Guan, S. Pan, “Adaptive sliding mode control of electro-hydraulic system with nonlinear unknown parameters,” Control Engineering Practice, Vol.16, no. 11, pp. 1275-1284, Nov. 2008.

[10] B. Beltran, T. Ahmed-Ali, M. El Hachemi Benbouzid, “Sliding mode power control of variable speed wind energy conversion systems,” IEEE Trans. Energy Conversion, Vol. 23, no. 2, pp. 551-558, June 2008.

[11] A. S. Morgans, A. M. Annaswamy, “Adaptive control of combustion instabilities for combustion systems with right-half plane zeros,” Combustion Science and Technology, Vol. 180. no. 9, pp. 1549-1571, 2008.

[12] C. James Li, H. S. M. Beigi, S. Li, J. Liang, “Nonlinear piezo-actuator control by learning self-tuning regulator,” J. Dyn. Sys., Meas., Control, Vol. 115, no. 4, pp. 720-723, 1993.

[13] S. W. Zhao, C. N.C., W. C. Gan, J. M. Yang, J. F. Pan, “ A self-tuning regulator for the high-precision position control of a linear switched reluctance motor,” IEEE Trans. Industrial Electronics, Vol. 54, no. 5, pp. 2425-2434, Oct. 2007.

[14] K. Yamashita, H. Miyagi, “ Multivariable self-tuning regulator for load-frequency control system with interaction of voltage on load demand,” Control Theory and Applications, Vol. 138, no. 2, pp. 177-183, Mar. 1991.

[15] Z. Salcic, J. Cao, S. K. Nguang, “A floating-point FPGA-based self-tuning regulator,” IEEE Trans. Industrial Electronics, Vol. 53, no. 2, pp. 693-704, April 2006.

[16] Y.H.Peng,” On the performance enhancement of self-tuning adaptive control” Int J Adv Manuf Technol, Springer, 2004, pp.395_403

[17] K.Astrom, B.Wittenmark, "Adaptive Control (2nd Edition)", Addison Wesley publishing company, pp.90-135.