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Model Identification Using Identification Tool and Estimation of Optimum Control Parameters Using Relay Tuning Method for Bioreactor

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Abstract

A mathematical Model for Bioreactor was developed and the simulated experimental data was used in Identification tool of MATLAB. The transfer function was identified using identification tool. The first order plus time delay (FOPTD) transfer function was obtained for bioreactor. The FOPTD model was used in SIMULINK and a relay feedback test was conducted to obtain a symmetric relay response. Then the Ziegler et al. [1] optimum controller parameter method and Padmasree et al. [2] method were used for estimation of optimum control parameters for the bioreactor system.

Keywords: Model identification; Relay tuning; Control parameters; SIMULINK; Bioreactor

Introduction

Control plays a key role in the operation of chemical plants with respect to economical performance, safety and operability. To realize the role of control at a general level, the definition of the concept “chemical process” [3] is “Chemical process is control of (physico-chemical) phenomena for a purpose”. This definition clearly shows the necessity of control: without control there would be no functional chemical process industry.

In a typical chemical plant there are hundreds of PID feedback loops. They are often poorly tuned because the choice of PID controller parameters requires professional knowledge by the user. The theory of controller tuning involves sophisticated mathematical manipulations, including complex-valued functions, differential equations, and integral transforms. It is thus not a surprise that the average process engineer repeatedly tunes controllers by trial-and-error methods. Because the PID controller has three tuning parameters, controller tuning by trial and error is a search in the three dimensional space. Evidently, optimal controller parameters are seldom instantly obtained by trial and error. Many modern controllers are equipped with various adaptive techniques such as self-tuning, on-line tuning and autotuning. These features provide easy-to-use controller tuning and have proven to be well accepted among process Engineers.

Identification of transfer function models from experimental data is essential for model based controller design. Often derivation of a rigorous mathematical model is difficult due to the complex nature of chemical processes. Hence, system identification is a valuable tool to identify low order models, based on input–output data. Astrom and Hagglund [4] have suggested the use of relay feedback test to generate sustained oscillations of the controlled variable and to get the ultimate gain (Ku) and ultimate frequency (ω_u) directly from the experiment. The relay feedback method has become very popular because it is time efficient as compared to the conventional method. Here, the Ziegler–Nichols continuous cycling method [1] is considered as a conventional method. The method is a closed loop method and the controller is a proportional one. The proportional gain is increased until sustained oscillations are obtained at the output for a unit step change in the set point. The gain (Ku) and the period of oscillation (Pu) in the output are noted and the controller is designed using Ziegler–Nichols tuning formulae as shown in Table 1. The conventional method requires several experiments. The relay feedback is a single shot experiment and the magnitude of oscillations can be varied. From the principal harmonics approximation, the ultimate gain and ultimate frequency are found. The ultimate gain and ultimate frequency are found from the principal harmonics approximation as given by equations (1) and (2).

$$\omega_u = \frac{2\pi}{p} \quad (1)$$

$$k_u = \frac{4h}{\pi a} \quad (2)$$

Luyben [5] has suggested the use of relay testing for identifying a transfer function model. Using the values of Ku and ω_u in the phase angle and amplitude criteria for first order plus time delay (FOPTD) model, we get the following two equations relating the three parameters.

$$\tau_d \omega_u - \tan^{-1}(\tau \omega_u) = -\pi \quad (3)$$

$$\frac{K_u K_P}{\left(1+\tau^2 {\omega_u}^2\right)^{0.5}} = 1 \quad (4)$$

Since only Ku and ω_u are available, the additional information such as steady state gain or time delay should be known a priori in order to fit a typical transfer function model such as a first order plus time delay model. Many methods are proposed for obtaining the additional information. Li et al. [6] have suggested the use of two relay tests. The first one is a relay test on the system and the second one on the system with a known dynamic element (additional dead time) inserted in

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the loop. However, the use of additional relay test is tedious and time consuming. An excellent review of relay feedback methods is given by Yu [7]. Shen et al. [8] have used a biased relay test for getting the model parameters using a single relay test. Friman and Waller [9] have proposed the use of two-channel relay test (one operating on process output and other on the integral of the process output). Scali et al. [10] have extended the technique suggested by Li et al. [6]; which assumed the delay of the process to be known, to estimate models with up to five parameters by means of a maximum of three relay tests with additional of different time delays. Luyben [5], Thyagarajan and Yu [11] have proposed a method that includes the effect of the shape factor in identifying the process model parameters.

Srinivasan and Chidambaram [12] have proposed a modified asymmetrical relay feedback method to get improved estimates of the parameters of the FOPTD model. Using a single asymmetrical relay test, a method is suggested for formulating additional equations to evaluate all the three parameters of the FOPTD model. The asymmetric relay method requires an extra parameter (γ, displacement in the relay height) and whose value is to be selected appropriately so that the calculation of the process gain and the estimate of ω_u are carried out accurately [8]. In the symmetric relay test such problems are not present. Vivek and Chidambaram [13] proposed a method to estimate the three parameters of an FOPTD model using a single symmetrical relay feedback method.

In present work, a mathematical Model for Bioreactor was developed and the simulated experimental data was used in Identification tool of MATLAB. The first order plus time delay (FOPTD) transfer function was obtained for bioreactor. The FOPTD model was used in SIMULINK and a relay feedback test was conducted to obtain a symmetric relay response.

Then the Ziegler-Nichols optimum controller parameter method and Padmasree et al. [2] method were used for estimation of optimum control parameters.

Materials and Method

A Bioreactor system was considered as shown in Figure 1. Biochemical reactors are cylindrical culture vessels used for the fermentation process in which anaerobic breakdown of complex organic materials by the action of anaerobic microorganism or free enzymes takes place. Materials such as carbon, nitrogen, oxygen, which are called substrate, and other nutrients are brought with the cell into the culture vessel (bioreactor) and converted within the cell via hundreds of reactions to the various constituents of the cell as well as to biochemical product. Bioreactors provide a controlled environment that is necessary to bring the better growth of microbes, and also maintain constant temperature according to the need of microbes. The method of identification of an unstable FOPTD system is applied to a nonlinear continuous bioreactor that exhibits output multiplicity. Initially, the system was assumed to be at the unstable steady state condition. The dilution rate (D) is considered as the manipulated variable in order to control the cell mass concentration (X) at the unstable steady state. A delay of 1h was considered in the measurement of X. For the given condition of the unstable operating point, the local linearized model is obtained as an unstable FOPTD with the parameters.

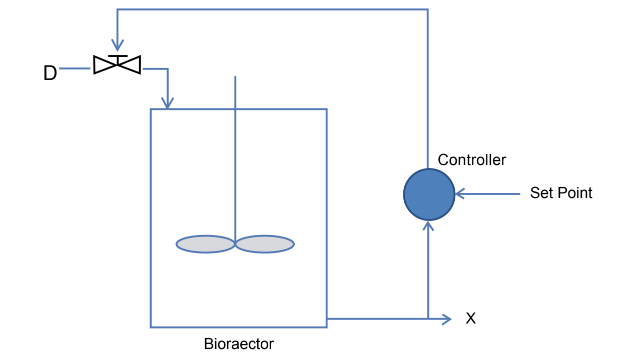

Figure 1: A completely mixed bioreactor.

Modeling of bioreactor

The dynamics of a completely mixed tank reactor were considered as shown in Figure 1. The influent flow rate is equal to the effluent (output) flow rate i.e. Fi=F [volume/time]. Hence, the volume V is constant. The influent has a substrate concentration Sin [mass/volume] and cell concentration X in [mass/volume]. The rate of accumulation of biomass is obtained from a mass balance. Assuming that the biomass has a specific growth rate μ. The total amount of produced biomass per time unit in a reactor with volume V is μVX. Since the reactor is completely mixed, the outflow concentration of biomass is equal to the concentration in the tank. The rate of change of biomass is then given as;

$$V\frac{dX}{dt} = \mu VX + FX_{in} - FX \qquad (5)$$

Now defining the dilution rate;

$$D = \frac{F}{V} \qquad (6)$$

The model [5] can be written as

$$\frac{dX}{dt} = \mu X + D(X_{in} - X) \qquad (7)$$

For the substrate consumption we assume that the yield coefficient is Y. Paralleling, the procedure above for the substrate mass balance gives;

$$V\frac{dS}{dt} = FS_{in} - \frac{\mu}{y}VX - FS$$

Where S is substrate concentration.

Introducing the dilution rate from equation (6);

$$\frac{dS}{dt} = -\frac{\mu}{y}X + D(S_{in} - S) \qquad (8)$$

Next it is considered the condition when μ is a Monod function;

$$\mu = \frac{\mu_0 S}{K_M + S + K_I S^2} \qquad (9)$$

Where Km is substrate saturation constant and *KI* is substrate inhibition constant.

In the case the influent flow rate is different from the effluent flow rate; the volume variation in the reactor needs to be taken into account;

$$\frac{dV}{dt} = F_i - F \qquad (10)$$

A mass balance for the biomass yields;

$$\frac{d}{dt}(VX) = \mu VX - FX \qquad (11)$$

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By applying chain rule and rearranging the above equation;

$$V\frac{dX}{dt} = \mu VX - F_i X \tag{12}$$

Introducing dilution rate in equation (12);

$$\frac{dX}{dt} = (\mu - D)X \tag{13}$$

Equations (8], (9) & (13) are the model equations. These equations were solved to get the transfer function of the system.

Result and Discussion

In the present control study the parameters used for a substrate inhibition model are μo = 0.53 h^{-1}, Km = 0.12 g/l, K_I = 0.4545 l/g, y = 0.4, Xin = 4.0 g/l, & D = 0.3 h^{-1}

The transfer function between the controlled variable (Biomass concentration, X) and manipulated variables (dilution rate, D) obtained is given by equation;

$$G_p(s) = \frac{\exp(-s)}{0.45s+1} \tag{14}$$

The model equations and transfer function obtained are used to obtain the simulated experimental data. The experimental data was used in Identification tool of MATLAB. The identification window and process model window are shown in Figure 2. The transfer function was identified by the identification tool and is given as

$$G_p(s) = \frac{1.03\exp(-1.5s)}{0.5s+1} \tag{15}$$

The step response, frequency response, best fit model window, residual model, Poles & Zeros and noise spectrum are shown in Figure 3 to Figure 8 respectively.

The Simulink implementation of the relay auto tuning procedure is shown in Figure 9; whereas the Relay & process response obtained from the application of this automatic tuning procedure is depicted in Figure 10 and Figure 11.

The ultimate gain (Ku), period of oscillation (Pu) and frequency of oscillation (ω_u) were obtained from the relay response.

Hence, h =05; a =0.44; Pu =2.5; ω_u=2.51,

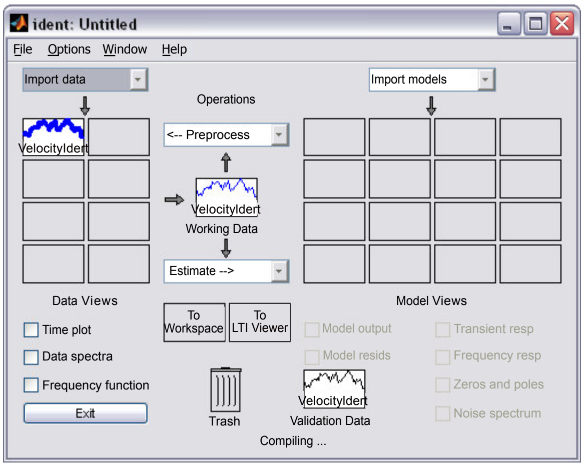

Figure 2: Identification window.

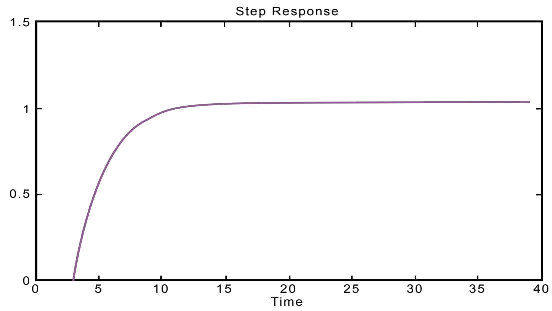

Figure 3: Step Response.

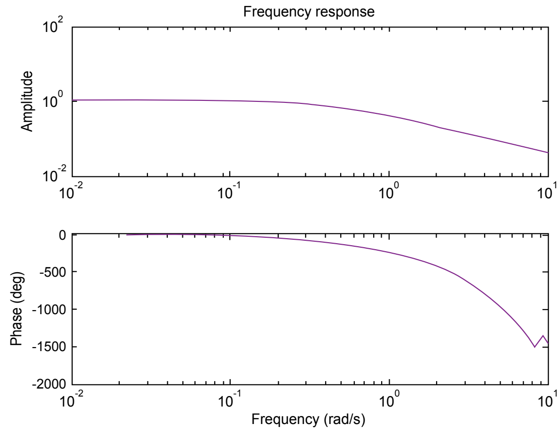

Figure 4: Frequency Response.

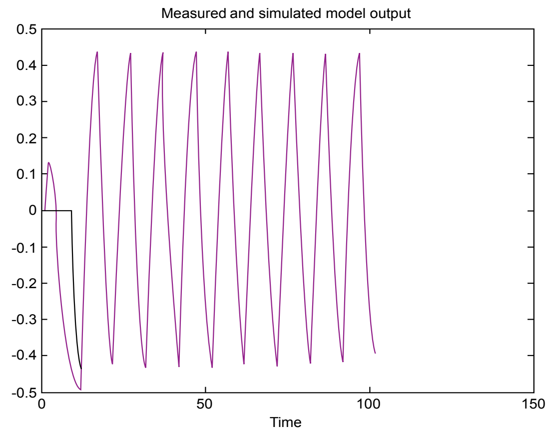

Figure 5: Best fit model.

Ku =1.44

The PID controller tuning parameters were calculated using Ziegler et al. [1] optimum controller parameter method as shown in Table 1.

Parameter

Then Padmasree et al. [2] method was used to calculate the PID parameters for FOPTD model as;

$$k_c k_P = \frac{\tau}{\tau_d} + 0.5\tau_d \tag{16}$$

$$\tau_I = \tau + 0.5\tau_d \quad (17)$$

$$\tau_D = \frac{0.5\tau_d\left(\tau + 0.1667\tau_d\right)}{\tau + 0.5\tau_d} \quad (18)$$

The Simulink implementation of the closed-loop feedback control system is shown in Figure 12; whereas the closed-loop response obtained using a PID control system is depicted in Figure 13.

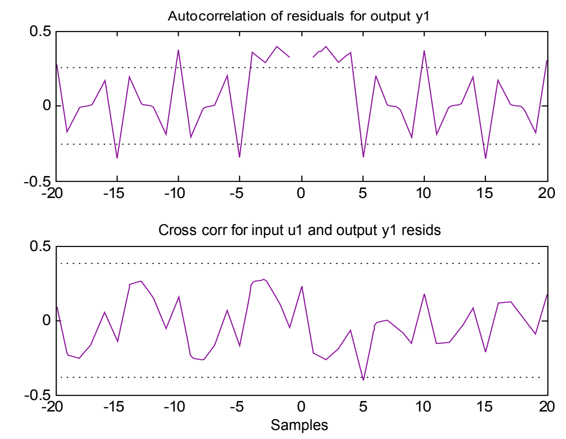

Figure 6: Residual model.

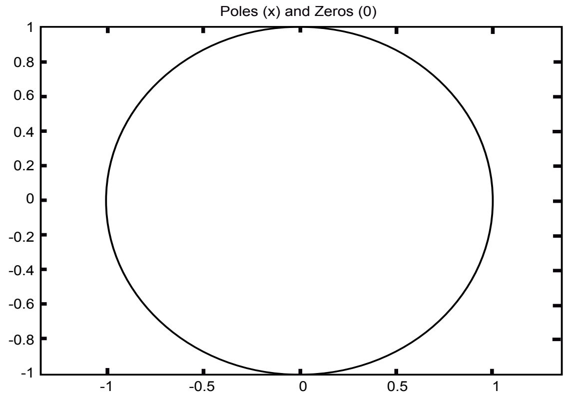

Figure 7: Poles & Zeros.

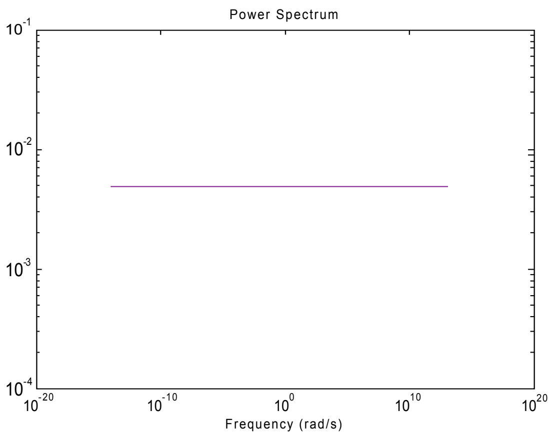

Figure 8: Noise Spectrum.

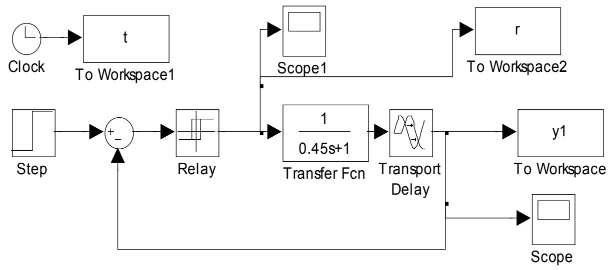

Figure 9: Simulink Diagram of Closed loop using Relay.

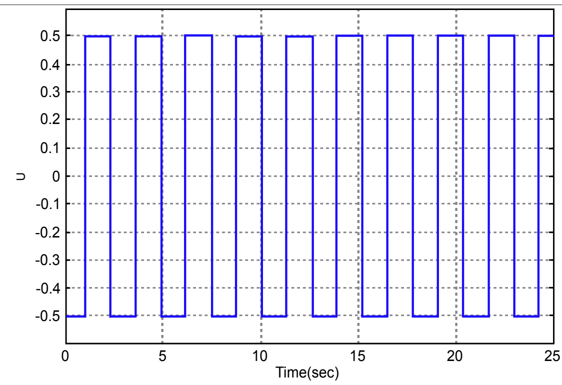

Figure 10: Relay Response.

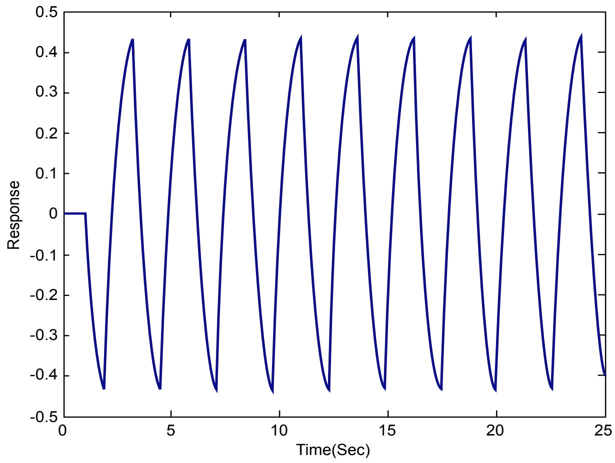

Figure 11: Process Response.

The PID parameters calculated by both the methods are shown in Table 2.

Conclusion

Simulated experimental data was used in Identification tool of MATLAB. The transfer function was identified using identification tool. The first order plus time delay (FOPTD) transfer function was obtained for bioreactor. A relay method is proposed, for estimating the ultimate gain and consequently the control parameters of FOPTD transfer function model of Bioreactor using a single symmetric relay test. The advantages of this method are: single relay feedback test and the PID parameters can be identified [13]. This method of identification is simple and will be of much industrial use. The present method can be

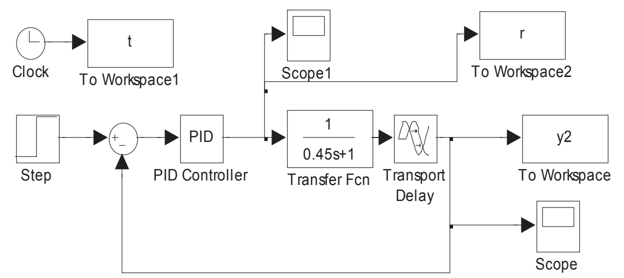

Figure 12: Simulink Diagram of Closed loop using PID.

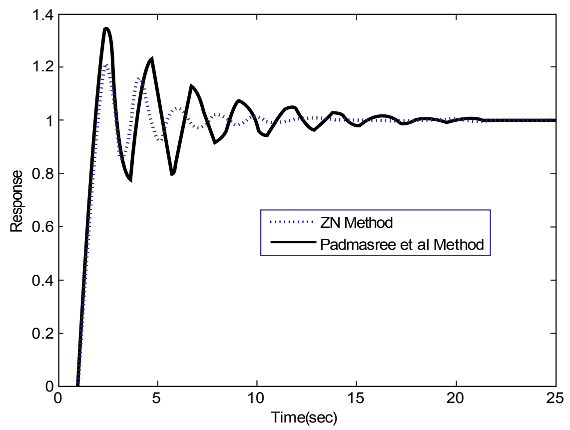

Figure 13: Process Response with tuned parameters.

Controller	Kc	τ_I	τ_D
P	0.5Ku	-	-
P+I	0.45Ku	$\frac{Pu}{1.2}$	-
P+I+D	0.6Ku	$\frac{Pu}{2}$	$\frac{Pu}{8}$

Table 1: Ziegler-Nichols optimum controller.

Controller	Kc	τ_I	τ_D
ZN method	0.86	0.8	0.31
Padmasree et al. method	0.95	0.95	0.38

Table 2: Control Parameters by both methods.

applied to higher order processes.

The control parameters obtained by Ziegler et al. [1] method and Padmasree et al. [2] method and compared and found close values for Bioreactor control.

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