Tuning of PID Controller for Biochemical Reactor using IPSO Algorithm

[1]Ompriyadharshni. K [2]Jabathira. A [3]Maheshwari. B [4]Akshaya. N
[1,2,3,4]Department of Electrical and Electronics Engineering
[1,2,3,4]St. Joseph's College of Engineering, Chennai 600119, Tamilnadu, India

Abstract

This paper addresses an improved PSO algorithm based PID controller tuning for a model biochemical reactor. Biochemical reactor is a highly nonlinear process and exhibits multiple steady states. To increase the productivity and to achieve the required performance, it is necessary to use optimised PID controller parameters. The work presented in this article, deals with the I-PD based controller design using PSO algorithm in order to minimise the effect of proportional and derivative kick. The gain (set point) scheduling is simulated with a switching unit controlled by a comparator. The simulation result shows a better performance for set point tracking and disturbance rejection.

Keyword- Biochemical Reactor, PID, PSO, Scheduling

I. INTRODUCTION

In chemical process industries, the contribution of Proportional + Integral (PI) or Proportional + Integral + Derivative (PID) takes up a major part, since it provides robust, optimal performance and also its simple structure. It can be easily realizable in analog and digital form. Ideal PID structures contribute widely in theoretical analysis. Real time applications are less supported due to constraints in implementation [6, 8]. Models such as PID (series / parallel), PID with filter, I-PD and ID-P structures are widely employed to enhance the present performance strategies in control areas.

Various model based studies on fine tuning of PID controllers has provided insight for understanding the controller performance. The model based methods seems to be complex, since its performance depends on an approximated process structure and also the requirement of process details such as ultimate gain (Ku) and Ultimate period (Pu). In addition, unique methodology for model identification does not exist. Further, precise model identification for real time processes appears to be complicated. The real time processes are accounted as low order associated with time delay models as first order or second order time delayed models [7]. Autotuning of PID parameters are widely used in industrial and research area. An ideal / modified relay feedback can be used to identify the approximate process model and also the values of Ku and Pu. For open loop unstable system, the application of relay tuning is limited by delay time (d) / process time constant (τ). Tuning the PID for open loop stable system model is simple and a number of tuning formulae is available [1, 6, 7, 11]. For open loop unstable systems, the controller tuning is very complicated and at time it is impossible to obtain the desired closed loop response due to the mismatch between the real process and approximated model. Due to these constraints, a model free method is widely preferred for controller tuning.

Controller design for the chemical process loop is one of the major research areas in the field of process control. Process control loop such as Continuous Stirred Tank Reactor (CSTR), biochemical reactors, distillation columns, has multiple steady states. Controller design for such loop is very difficult and it may require traditional tuning methods along with advanced technique such as Internal Model Control (IMC), Model Predictive Control (MPC), Neural Network (NN), Fuzzy, Adaptive Neuro Fuzzy Inference System (ANFIS), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm. The advanced control technique such as MPC, the importance of PID control has been enhanced, because MPC is most often constructed hierarchically with PID controllers at the lower regulatory layer, and well-tuned PID controllers are prerequisites for successful advanced control implementation [4].Real time implementation of Neural Network based controller is a challenging task.

Tuning a PI/PID controller for a system with multiple steady states is a challenging field. This can be achieved by a gain scheduler. It can be used to control processes at different operating points with differing dynamics. This system consists of a family of local controllers and a switching unit (scheduler). This switching unit is used to activate the controller depending on the operating region. The particular operating region can be scheduled based on the set point (or) based on the plant operating time/value [10].

For all the PID structure, the main goal is to find optimal values of the controller parameters to achieve the required closed loop performance.

Bioreactor control was widely studied by the researchers due to its importance in chemical and biochemical engineering. Recently a PSO based PID was proposed for an unstable bioreactor and it is observed that it has a P and D kick [7]. In this study, an Improved PSO algorithm is attempted to control a biochemical reactor with I-PD controller structure.

II. BIOCHEMICAL REACTOR

The biochemical reactor is an essential unit operation in a wide variety of biotechnological processes. In this system, living cells are used to produce marketable intermediate and final products, including chemicals, medical products, food products, beverages, and industrial solvents with the help (process) of biosynthesis. In a basic reactor, the major components are biomass and substrate. The biomass consists of cells, consume the nutrients (substrate) to grow and produce more cells and important products. The cell also produces energy and more cells from the nutrients [3].

The basic reaction inside the bioreactor is Substrate + Cell ----→ More cells + Products

The stoichiometry for cell growth is very complex and varies with nutrient, pH, temperature and redox potential and in this study nutrient based cell growth is considered and the other variables are assumed as constant.

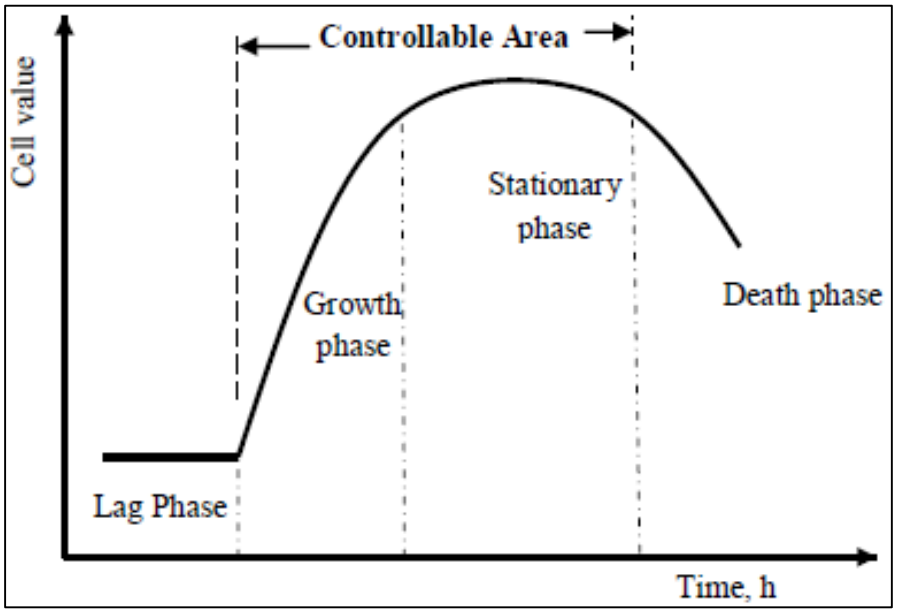

Fig. 1: Various working stages of a Biochemical Reactor

Fig.1 shows the working stages of a basic Biochemical reactor. The various stages are given below: Lag phase: Adjustment of cell to new environment and getting ready to begin reproduction
Growth phase: By using the nutrients', the cells grow and cell's growth rate is proportional to concentration
Stationary phase: Cell's growth rate stopped and products are produced
Death phase: Decrease in live cell concentration occurs.
From Fig.1, it is necessary to implement the controller in growth and stationary phase, to achieve maximum production.
For biochemical reactors, unstructured models are mainly considered for its simplicity. The following models can describe a variety of bioreactors and schematic of the reactor is shown in fig.2.

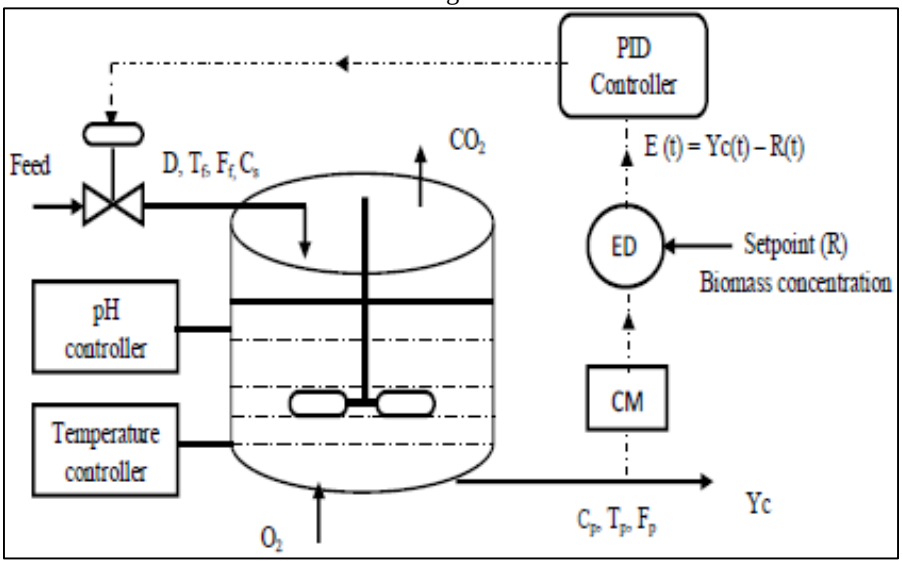

Fig. 2: A complete structure of a Biochecmical Reactor

$$\mu = \frac{\mu_{max}\ x_2}{k_m + x_2 + k_1 x_2^2} \quad \text{Substrate Inhibition} \qquad (3)$$

Where x_1 is biomass (cell) concentration, x_2 is substrate concentration, D is the dilution rate, x_{2f} is substrate feed concentration. For substrate inhibition model, the following parameters are considered [11].
μ max = 0.53 hr^{-1}, km = 0.12g/l, k1=0.4545 l/g, Y = 0.4. The steady state dilution rate is Ds = 0.3 $^{h-1}$ (the residence time is 3.33 h) and the feed substrate concentration is x_{2fs} = 4.0 g/l. The nonlinear process has the three steady state operating points for a dilution rate of 0.3 $^{h-1}$

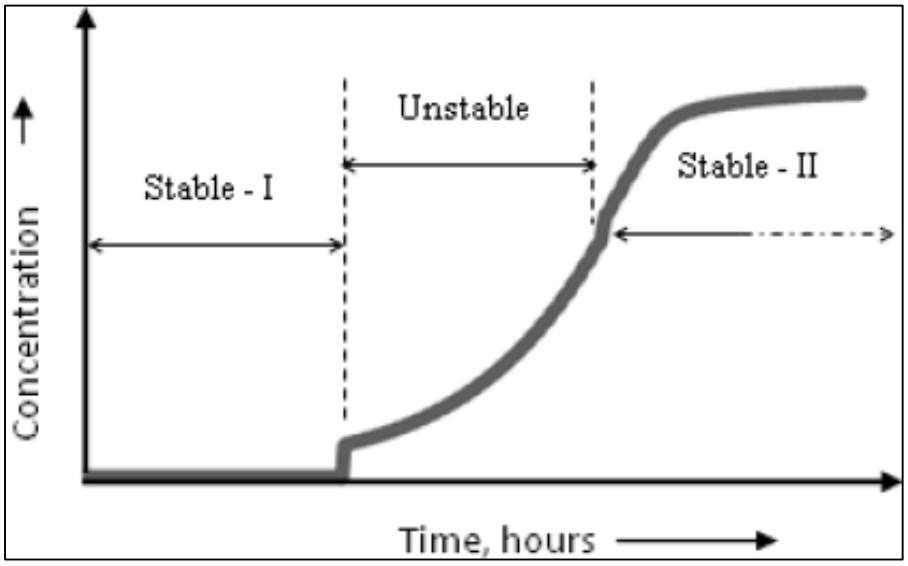

Fig. 3: Variation of Biomass concentration X with time and S

Steady state	*Biomass Concentration (g / lit)*	*Substrate concentration (g / lit)*	*System's condition*
Wash out	*0*	*4.0*	*Stable*
Nontrivial	*0.995103*	*1.512243*	*Unstable*
Nontrivial	*1.530163*	*0.174593*	*Stable*

Table 1: Steady state conditions for Biochemical reactor

III. PSO

The PSO algorithm attempts to mimic the natural process of group communication of individual knowledge, to achieve some optimum property. The swarm is initialized with a population of random solutions. Each particle in the swarm is a different possible set of the unknown parameters to be optimized. Representing a point in the solution space, each particle adjusts its flying toward a potential area according to its own flying experience and shares social information among particles. The goal is to efficiently search the solution space by swarming the particles toward the best fitting solution encountered in previous iterations with the intent of encountering better solutions through the course of the process and eventually converging on a single minimum error. At the beginning, each particle of the population is scattered randomly throughout the entire search space. Under the guidance of the performance criterion, particles in their flies dynamically adjust their velocities according to their own flying experience and their companions flying experience.

Each particle remembers its best position obtained so far, which is denoted pbest. It also receives the globally best position achieved by any particle in the population, which is denoted as gbest . The updated velocity of each particle can be calculated using the present velocity and the distances from pbest and gbest [5].
The mathematical expression for improved velocity update [2]

$$Vi(k+1) = Wi \times Vik + C1 \times R1 \times (pbest - Sik) + C2 \times R2 \times (gbest - Sik) + C3 \times R3 \times (gbest - Sik) \quad (4)$$

Where,

V_{ik}- current velocity of particle i at iteration k,

$V_{i(k+1)}$ -updated velocity of particle i,
Wi - different inertia weight of particle i
C_1, C_2, C_3 - positive constants,
Sik- current position of particle i at inertia k,
R_1, R_2, R_3 -random number between 0 and 1,
The new position can be modified using the present position and updated swarm position is

$$Si\ (k+1) = Sik + Vi\ (k+1) \qquad (5)$$

A. Algorithm

Step1. Set values for N, D, C1, C2, C3, Wmin, Wmax and Overshoot range
Step2. Initialize a population of particles with random positions and velocities on D – space
Step 3. Evaluate the objective function of every particle and record each particle's pbest and gbest. Evaluate the desired optimization fitness function for each particle in D – variables.
Step 4. Compare the fitness of particle with its pbest . Replace pbest with the current value and pi with the current location xi, if the current value of the particle is better than pbest.
Step 5. Change the current velocity and position of the particle according to Equation (4) and (5)
Step 6. Loop (to step 3) until a criterion is met.
Step 7. Measure the overshoot (Yout – Input). If the overshoot is within the specified range. Stop the search and display the values of Kp, Ki, Kd. Otherwise retune the Kp or Ki based on the given performance criteria.
The parameter Wi is inertia weight that increases the overall performance of PSO. The larger value of Wi can favour for global search and lower value of Wi implies a higher ability for local search. To achieve a higher performance, the linearly decreased value of inertia is proposed by You-Bo Wang .et.al [14] according the following formula.

$$Wi = W\,max - Iter \times [(W\,max - W\,min) / (Iter\,max)] \quad (6)$$

is considered.
The simulation is carried out by using W min = 0.3 and W max =1.5 and it is found that the iteration time required is more (58sec). To minimize the iteration time, an intermediate value of Wi =0.5 is used. The PSO algorithm is simulated with the following values. The positive constants C1 =2, and C2 =1.5, C3 = 2, size of the swarm is 25, and the dimension of the problem is 3 (ie. Kp, Ki & Kd). The three dimensional search space for Kp, Ki and Kd is selected as kp ε [Kp (1-20%), Kp (1+20%)], ki ε [Ki (1-20%), Ki (1+20%)], kd ε [Kd (1-20%), Kd (1+20%)].

PSO is a search algorithm which finds the optimum controller values based on the Error (ISE / IAE / ITAE). In this paper the ISE based optimization is attempted. A new retuning concept is used to minimize iteration time with initial overshoot measurement.

$$Overshoot = Yout - Input$$

If the overshoot is greater than the specified range (5 % to 20 %), a retuning concept is utilized to adjust the P or I parameters (Refer. step 7 in Algorithm).

IV. RESULTS AND DISCUSSIONS

Fig.4. shows the block diagram of the online improved PSO based I-PD controller tuning with a PID switching unit. Minimization of ISE is considered in this paper to tune the PID using PSO.
PID1 is the tuning parameters for unstable steady state and PID2 is the value of stable steady state.

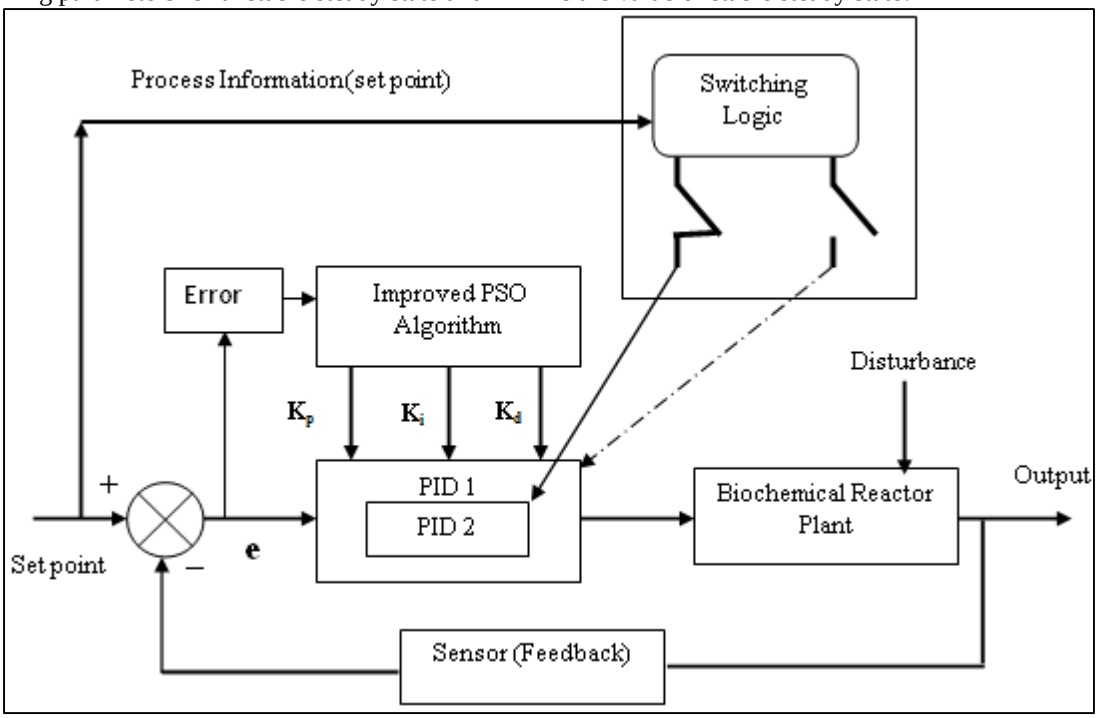

Fig. 4: PSO based I-PD controller with set point based gain scheduler

V. A. TUNING PID1

Let us consider the following unstable steady state model.

$$\frac{\Delta X(s)}{\Delta D(s)} = \frac{K \exp^{-ds}}{(\tau s - 1)} = \frac{-5.89 \exp^{-1s}}{(5.86s - 1)} \qquad (7)$$

Eqn.8 shows the structure of I-PD controller, widely used in industry to reduce the effect of Proportional and Derivative kick. This structure can be easily realized by modifying the structure of a simple PID controller. In this 'I' responds to the error signal and the P and D responds to the Process Variable (PV).

$$\text{I-PD Controller} = K_p(-PV) + K_i \int e\,dt + K_d \frac{d(-pv)}{dt} \qquad (8)$$

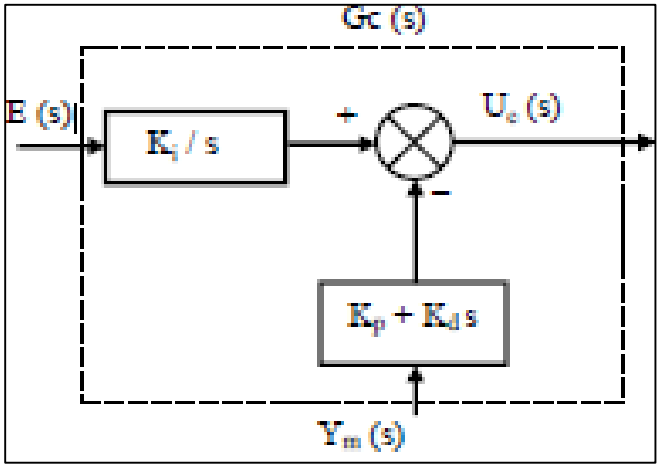

Fig. 5: Block diagram of I – PD controller structure

The simulated result gives the following Kp , K i, Kd Values as Kp = -0.6182, Ki=-0.0928, and Kd = - 0.1210.

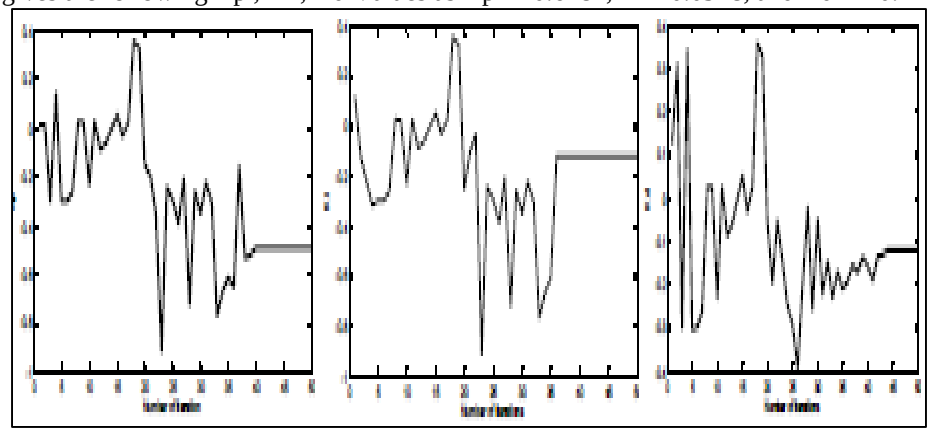

Fig. 6: Converged Kp, Ki and Kd values respectively

VI. B. TUNING PID2

For the stable steady state, the following transfer function model is considered.

$$\frac{\Delta X(s)}{\Delta D(s)} = \frac{K \exp^{-ds}}{(\tau s + 1)} = \frac{-0.6758 \exp^{-1s}}{(0.4417s + 1)} \qquad (9)$$

The values of PID parameters are Kp = -1.4371, Ki = -1.0931, Kd = - 0.3085.

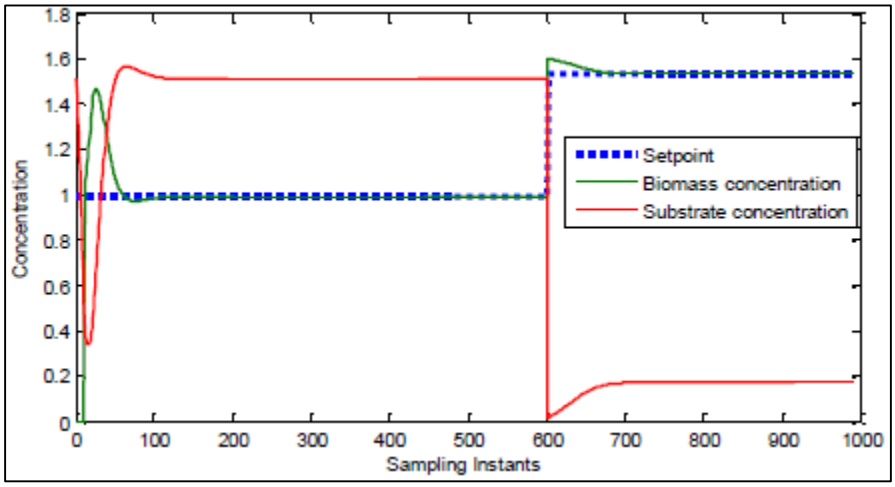

Fig. 7: Gain scheduled control of biochemical reactor – Servo response

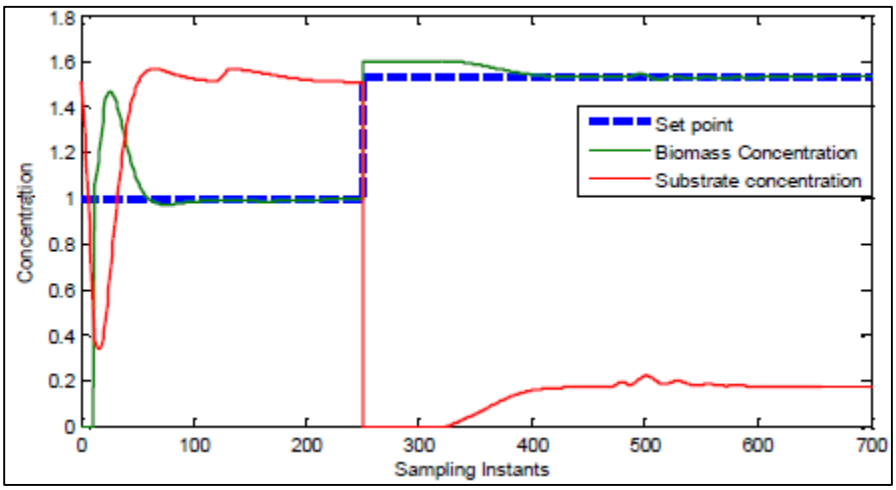

Fig. 8: Gain scheduled control of biochemical reactor – Regulatory response

Fig.7 and 8. Shows a very smooth servo response of the biochemical reactor with a gain scheduled PSO:I-PD controller.
Initially the bioreactor is in lag phase without any controller.
The controller is introduced during the growth space and it monitors the bioreactor up to the stationary phase. The initial growth rate is very rapid and it may produce an overshoot due to the nonlinear behaviour.

VII. CONCLUSIONS

In this work, an improved PSO algorithm was attempted to identify an optimal I-PD controller parameters. The proposed controller structure has single degree of freedom (DOF). The result shown in the simulation for the regulatory response is not smooth. This problem can be minimized by using a 2 DOF PID structure. The major merit of this method is the computation time is smaller than the basic PSO, the retuning can help to get a better controller parameter and the effect of proportional and derivative kick is nullified.

REFERENCES

[1] Aidan O'Dwyer. (2009). Hand book Handbook of PI and PID controller tuning rules, 3rd Edition, Imperial College Press, London.
[2] Chang, W-D., and Shin, S-P. (2010), PID controller design of nonlinear systems using an improved particle swarm optimization approach , Communications in Nonlinear Science and Numerical Simulation, Elsevier, Volume 15 (11), 3632-3639.
[3] Giriraj Kumar, S.M., Jain, R., Anantharaman, N., Dharmalingam, V., and Sheriffa Begam, K.M.M.(2008). Genetic Algoritha Based PID Controller Tuning for a Model Bioreactor, Indian Institute of Chemical Engineers, Vol.50, No.3, 214-226.
[4] Hiroya Seki, and Takashi Shigemasa. (2010). Retuning Oscillatory PID control loops based on plant operation data, Journal of Process Control, 20, 217-227.

[5] Kennedy, J and Eberhart, R.(1995). Particle Swarm Optimization, in proceedings of IEEE International Conference on Neural, 1942- 1948.
[6] Michael A. Johnson, Mohammad H. Moradi. (2005).PID Control: New Identification and Design Methods, Springer-Verlag London Limited.
[7] Padma Sree, R. and Chidambaram, M. (2006). Control of Unstable Systems, Narosa Publishing House, India.
[8] Panda, Ramesh C. (2009). Synthesis of PID controller for unstable and integrating processes, Chemical Engineering Science, 64, 2807-2816.
[9] Rajinikanth,V., Latha, K.(2010). Identification and Control of Unstable Biochemical Reactor, International Journal of Chemical Engineering and Applications, Vol. 1, No. 1,106 -111.
[10] Sabura Banu, U., and Uma,G.(2008).Fuzzy Gain Scheduled Continuous Stirred Tank Reactor with Particle Swarm Optimization based PID control Minimizing Integral Square Error, Instrumentation Science & Technology, Volume 36 (4), 394 – 409.
[11] Wayne Bequette, B. (2003). Process Control – Modeling, Design and Simulation, Prentice – Hall of India Pvt Ltd.
[12] You-Bo Wang, Xin Peng, and Ben-Zheng Wei. (2008). A New Particle Swarm Optimization Based Auto-Tuning of PID Controller, in proceedings of 7th International Conference on Machine Learning and Cybernetics, IEEE press, pp.1818-1823.