DESIGN OF OPTIMAL DISTURBANCE REJECTION CONTROLLER FOR CSTR USING PARTICLE SWARM OPTIMIZATION

[1]ANSHU SHARMA, [2]SHIV NARAYAN

Department of Electrical Engineering, PEC University of Technology, Chandigarh, India

Abstract-This paper proposes design methodology for a disturbance rejection optimal PID controller for Continuous stirred tank reactor (CSTR), posing the controller design problem as optimization problem and, then, solving it using particle swarm optimization algorithm (PSO). The performance index to be minimized is the H_2 - norm of the tracking error and constraint is the frequency domain performance of disturbance rejection. The problem boils down to the minimization of H_2 performance index under the inequality constraint of H_∞ norm of closed loop transfer function. The PSO is used to solve the constrained optimization problem.

Keywords- Disturbance rejection controller, CSTR, PID. Particle swarm optimization, global optimization, optimal

I. INTRODUCTION

The PID controllers have been in use for several decades [1-3]. In the design, three PID control parameters are tuned to achieve the desired performances. In last few decades, much attention has been focused on mixed H_2/H_∞ problems from theoretical view point [4-7]. The conventional designs based on mixed H_2/H_∞ optimal control are complicated and not easily implemented for practical industrial applications. In designing optimal disturbance rejection controllers with fixed structures both tracking behavior and disturbance rejection are considered. The controller design is formulated as constraint optimization problem.

CSTR offers diverse range of researches in the area of control and chemical engineering. Various control approaches have been applied on CSTR to control its parameters.

In this paper, a design methodology for disturbance rejection PID control is developed solving optimization problem using PSO for global optimization problem. The design of optimal disturbance rejection controller with fixed structure based on minimizing a performance index subject to the disturbance rejection constraint using H_∞ norms will be carried. Design is formulated as a minimization of the integral of squared error subject to disturbance rejection constraint.

II. CONDITION FOR DISTURBANCE REJECTION

Disturbance with deterministic signal form, e.g. step function, sinusoidal function, are assumed in the classical methods for controller design [4]. Taking into account disturbances using the H_∞-norm, the type of the signal can be arbitrary. It must be assumed, however, that the amplitude of the signal is bounded. In the following, the condition for disturbance rejection will be described. Consider the control system shown in the Fig. 1 with disturbance $D_y(s)$ acting at the plant output. The controller with fixed structure is given by a rational transfer function C(s). The plant is described by its nominal transfer function $G_o(s)$.

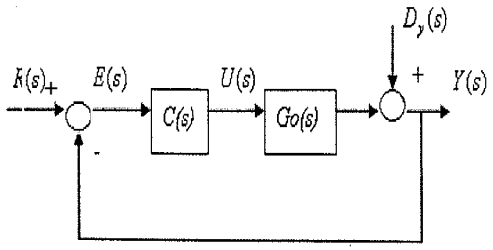


Fig.1 Control system with disturbance acting on the plant output

Let the reference signal $R(s) = 0$, then the relation of the controlled variable, Y(s), to the disturbance at the output, $D_y(s)$, can be described as follows:

$$\frac{Y(s)}{D_y(s)} = \frac{1}{1 + C(s,k)G_0(s)} \quad (1)$$

Applying Theorem 3.1 to equation (1) yields:

$$\max_{d_y(t)\in L_2} \frac{\|y\|_2}{\|d_y\|_2} = \left\| \frac{1}{1 + C(s,k)G_0(s)} \right\|_\infty \quad (2)$$

The condition for disturbance rejection indicates that the maximal amplitude of the output variable y(t) caused by means of the disturbance on the plant output $d_y(t)$, should not exceed a pre-fixed upper bound γ, i.e.

$$\max_{d_y(t)\in L_2} \frac{\|y\|_2}{\|d_y\|_2} = \left\| \frac{1}{1 + C(s,k)G_0(s)} \right\|_\infty < \gamma \quad (3)$$

Where, $\gamma \leq 1$ is a design parameter

The performance index is

$$\int_0^\infty e^2(t)dt \quad (4)$$

The optimal system is one that minimizes this integral. This criterion has a characteristic that in the unit-step response of the system a large initial error is weighed lightly, while errors occurring late in the transient response are penalized heavily.

III. PARTICLE SWARM OPTIMIZATION

It is a population based stochastic optimization technique developed in 1995 [8], from the simulation of social behavior of bird flocking or fish schooling. PSO has been found to be simple, effective and robust in solving problems with nonlinearity, non-differentiability and multidimensional optimization [9]. In PSO, each particle represents a candidate solution to the optimization problem. At the beginning, each particle spans randomly through the problem space and updates its velocity and position with the two best values. The first best value, called pbest is the best solution achieved so for. Another value, called gbest is the Global best solution obtained so far by any particle in the swarm. At each interaction, each particle moves to pbest and gbest locations. The cost function evaluates the performance of particles to determine whether the best solution is achieved. In the present thesis work, the PSO is used to solve the constrained optimization problem.

In PSO algorithms each particle moves with an adaptable velocity within the regions of decision space and retains a memory of the best position it ever encountered. The best position ever attained by each particle of the swarm is communicated to all other particles. The updating equations of the velocity and position are given as follows:-

A particle position is given by $x_i(k)$

A particle velocity is given by $v_i(k)$

A best "remembered" individual particle position is given by $p_i(k)$

A best "remembered" swarm position is given by $p_g(k)$

Cognitive and social parameters referred to as acceleration constants are given by c_1 and c_2.Random numbers between 0 and 1 are r_1 and r_2 .A inertia weight is given by w.P_i refers who best position found by particles. Velocity of Individual particle is updated as follows:

$v_i(k+1) = wv_i(k) + r_1c_1[\, p_i(k) - x_i(k)\,] + r_2c_2\,[\, p_g(k) - x_i(k)\,]$

Position of individual particle is updated as follows:

$x_i(k+1) = x_i(k) + v_i(k+1)$

The details of the PSO algorithm are given in flowchart.

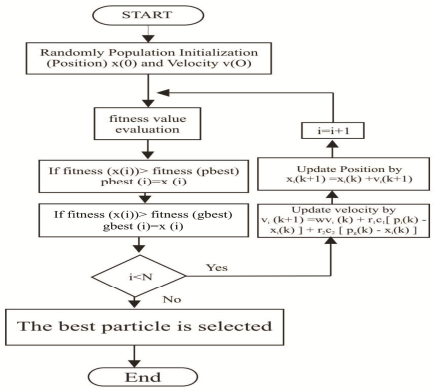


Fig.2 Flowchart of the PSO algorithm

IV. DESIGN EXAMPLE

To illustrate design of optimal PID controller for disturbance rejection a detailed design example is presented. Consider the control system shown in the Fig. 1 The model of plant is CSTR which is described by the following transfer function:

$$G_O(s) = \frac{2}{s^2 + 0.5s + .25}$$

The controller structure *C(s,k)* is taken as [4]

$$C(s,k) = k_p + \frac{k_i}{s} + sk_d \qquad (5)$$

The vector k of controller parameters is given by $k = [k_d, k_p, k_i]^T$, which is to be obtained solving the optimization problem. The weighing function $W_d(s)$ is taken as [4];

$$W_d = \frac{1}{s+1} \qquad (6)$$

The error signal *E(s),* assuming the input signal to be a unit step, is evaluated as follows:

$$E(s) = \frac{1}{1 + C(s,k)Go(s)}R(s) \qquad (7)$$

The squared error $J_5(k) = E'E$ is obtained.. This squared error is to be minimized under the disturbance rejection constraint. The H_∞ norm is calculated using MATLAB function normhinf.

The performance of the open loop plant without controller is shown in the Fig.3.

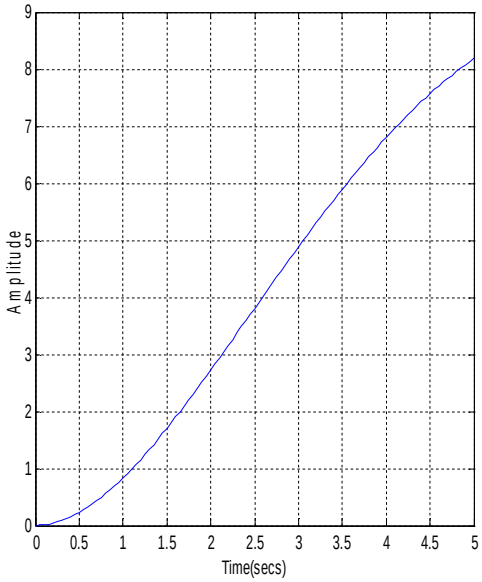


Fig.3 Step response of the plant without controller

Bode Plots of system without controller are shown in Fig.4. The gain and Phase margins are infinity and 1.3 deg. respectively.

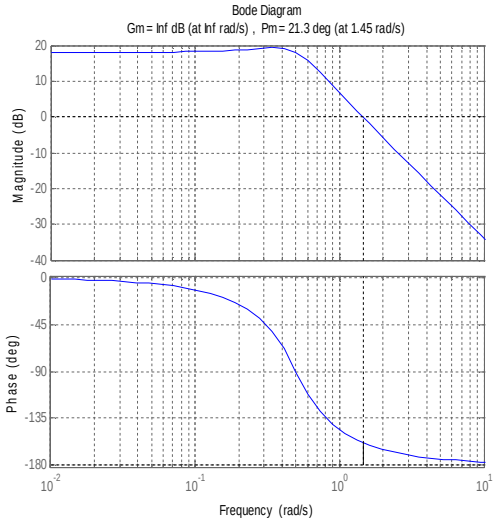


Fig.4. Bode plots of the system without controller

Performance index J_5 *(k)* is to be minimized is taken as ISE.J_5*(k)* has been minimized under the constraint of disturbance rejection.
The controller parameter vector was searched in the following bounds:
K_p= [0,40]; k_d = [0,30]; $k_{i=}$ [0,30];

The PSO algorithm converged with minimum value of J_5(k*) and optimal solution vector

k* =[15.0008 5.0001 .9994]]^T.

Bode plots of system with designed controller are shown in the Fig.5. The gain and phase margins are infinity dB and 142 deg. respectively.

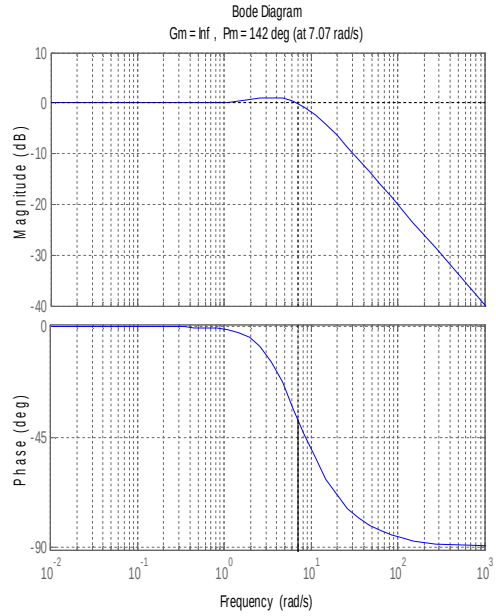


Fig. 5. Bode plots of system with the designed controller

The closed loop step response of the feedback control system shown in Fig.1 with the designed controller without disturbance is shown in Fig. 6.

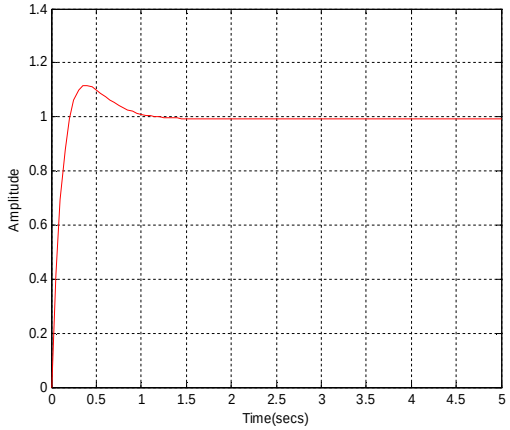


Fig.6 Step response of the controlled plant without disturbance

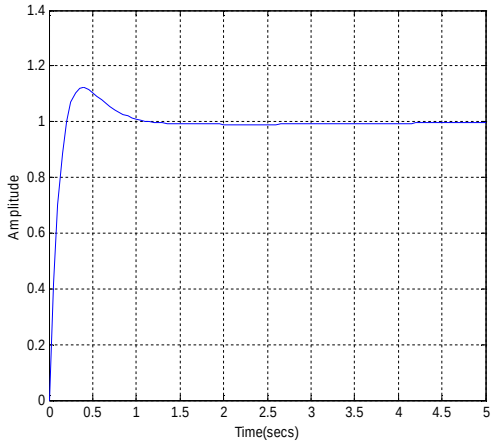


Fig.7. Step response of the controlled plant with disturbance

The performance of the control system in Fig. 1 with designed controller is compared with respect to closed-loop step response with and without disturbance. The tracking behavior of the control system with and without disturbance is shown in Fig. 8.

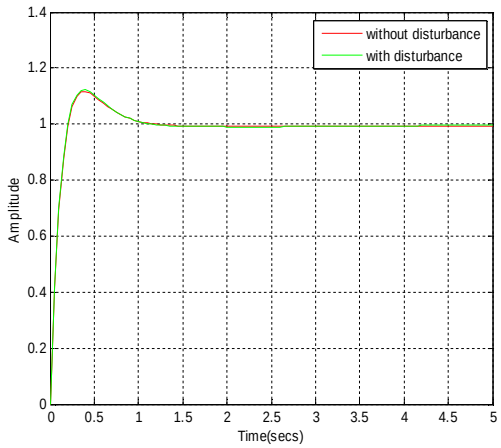


Fig.8. Step response of the controlled plant with and without disturbance

There is no difference between the two responses. The designed controller gives satisfactory response in the face of plant disturbance.

The following time domain performances have been achieved:
RiseTime: 0.1432
SettlingTime: 0.9255
SettlingMin: 0.9905
SettlingMax: 1.1218
Overshoot: 12.5201
Undershoot: 0
Peak: 1.1218
PeakTime: 0.4000

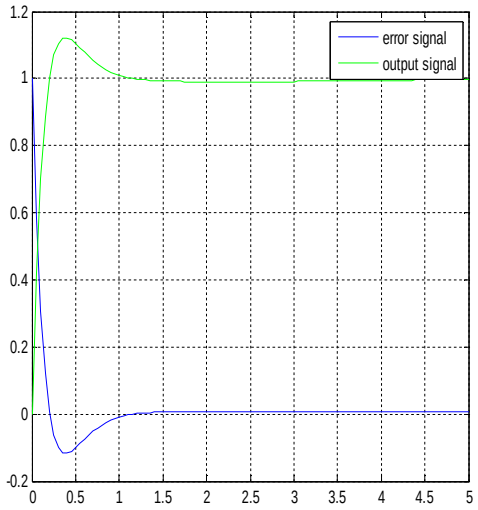


Fig..9. Step response of the error signal and output signal

CONCLUSIONS

In this paper a method is presented to design an optimal disturbance rejection controller for CSTR. The design problem is formulated as an optimization problem with constraint of type H_∞ norm.. The designed controller gives satisfactory response in the face of plant disturbance Therefore the proposed control algorithms are shown to be effective. In the future, this control method can be further extended and applied to multivariable system.

REFERENCES

[1] K.J. Astrom and C.C.Hang, W.K. Ho, "Towards Intelligent PID control'', Automatica,vol. 28, no. 1, pp.1-9,1992.

[2] C.C. Hang, K.J. Astrom and W.K. Ho,"Refinements of the Ziegler-Nichols tuning formula", IEEE Proc.-D,vol. 138,no. 2, pp. 111-118, 1991.

[3] K.J. Astrom and W. Mark,"Computer controlled systems: Theory and design", Prentice-Hall, Engle Wood Cliffs, NJ, 1990.

[4] M. Jamshidi, L.D.S. Coelho, R.A. Krohling and P.J. Fleming, "Robust control system with genetic algorithm," CRC Press, 2003.

[5] B.S. Chen, Y.M. Cheng and C.H. Lee,"A genetic approach to mixed H_2/H_∞ optimal PID control", IEEE Control Systems Magazines, pp. 51-59 ,1995.

[6] P.P. khargonekar and M.A. Rotea, "Mixed H_2/ H_∞ control: A convex optimization approach'', IEEE Transactions on Automatic Control, vol. 36,no. 7,pp. 824-837,1992.

[7] S. Tengchen, B.S. Chen and Y.P. Lin, "A mixed H_2/ H_∞ control design for linear time-varying systems: dynamic programming approach", Journal of Control system and technology,vol. 1, no. 1, pp.43-59,1993.

[8] J.Kennedy and R.C. Eberhark, "Swarm intelligence", Morgan Kaufmann, San Francisco, CA, 2001.

[9] L.H. Lin, F.C. Wang and J.Y. Yen, "Robust PID controller design using particle swarm optimization", Proc. of the 7th Asian Control Conference, Hong Kong, China, pp.1673 - 1678, Aug. 2009.

[10] L.H. Lin, F.C. Wang and J.Y. Yen, "Robust PID controller design using particle swarm optimization", Proc. of the 7th Asian Control Conference, Hong Kong, China, pp.1673 - 1678, Aug. 2009.

[11] D. H. Kim, "Hybrid GA-BF based intelligent PID controller tuning for AVR system," Applied Soft Computing Journal, vol. 11, no. 1, pp. 11–22, 2011.

[13] Tore Hägglund**,** "Signal Filtering in PID". Conf. of *IFAC* on Advances in PID Control, Brescia, Italy, March 2012.

★★★