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# Tuning of Fractional Order PI Controller for Cascade Control System using Genetic Algorithm

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## Abstract

**Background/Objectives:** The main objective of this research work is to design a cascade control system with fractional order proportional plus integral controller as the primary controller and proportional controller as the secondary controller. The best optimal values for fractional order PI controller (FOPI) controller are obtained by minimizing time integral performance criteria i.e IAE using genetic algorithm. **Methods/Statistical Analysis:** Cascade control scheme is one of the most popular control schemes in process industries because of its improved disturbance rejection and easy implementation. Research have been done by various researchers in designing the conventional controller for a cascade control system, but the emergence of fractional calculus in the field of control area paved the idea to replace conventional integer order controllers by fractional order controllers. Findings: The cascade control system is always designed using conventional controllers. An attempt is made to replace conventional integer order controllers in the primary loop with fractional order controllers in order to improve the performance and get better disturbance rejection. **Applications/ Improvements:** Simulation results show the effectiveness of the proposed controller. The performance indices tabulated and compared to indicate the improvement.

**Keywords:** Fractional Order PI Controller, Integral Absolute Error (IAE), Genetic Algorithm, Z-N Method

## 1. Introduction

Cascade control and feedforward with feedback control are two important control techniques to improve the disturbance rejection. Out of which cascade control finds advantage in process industries in order to improve the disturbance rejection[1-3]. The common example of cascade control system is continuous stirred tank reactor and polymerization reactor. Work has been carried out to control the reactor temperature using cascade control strategy[4,5]. Simultaneously tuning of cascade controllers tuned using desired closed loop response was proposed by the researchers[10]. Relay feedback based automatic tuning has been done for the cascade control system[11]. Few researchers worked on the applications of cascade control strategy to single input single output stable processes[12-14]. A control strategy for cascade control based on SISO multi scale control has been done[15]. Some researchers concentrate on the design of cascade control for unstable processes and SISO process with time delays which are quiet a challenging task[16-18]. Recent, application of fractional calculus finds importance in control area[19,20], for the fractional order controller design replacing the traditional integer order systems. In this paper, fractional order proportional integral controller is proposed and designed using genetic algorithm.

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## 2. Process Description

The setup shown in Figure 1 consists of a single transparent cylindrical process tank, overhead sump, pump, differential pressure transmitter, rotameter, control valve and interfacing card.

In cascade control action, the pump discharges the water from reservoir and gives it to rota meter and control valve. While the fluid flows through the orifice plate, a differential pressure developed across it, which is sensed by differential pressure transmitter corresponding current output (4-20 mA) is given to the Data acquisition system. Through the data acquisition card the process is linked to the computer, where the computer acts as error detector and controller. According to the error signal, corresponding control signal is given to the I/P converter. It controls the flow of the fluid in pipeline by varying stem position of the control valve. The level is a primary control loop and flow is a secondary control loop. For maintaining the level of the process tank, flow is manipulated level signal and is given to the Data acquisition system.

**Figure 1.** Setup diagram.

### 2.1 Input-Output Characteristics

The real time process data is collected considering as cascade loop. The step input of magnitude equal to 70% is applied and the data is logged. The process reaction curve of the process is shown in Figure 2.

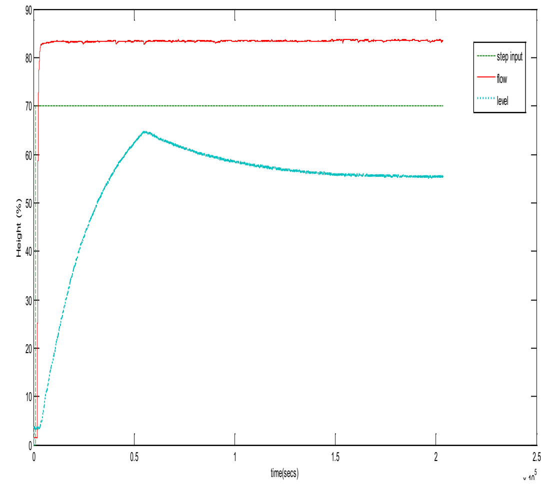


**Figure 2.** Open loop response curve.

From the curve the transfer function of the level loop and flow loop is found as,

$$G_{p1}(S) = \frac{0.66e^{-12.4s}}{146.68S + 1} \tag{1}$$

$$G_{p2}(S) = \frac{1.19e^{-8.5s}}{3.25S + 1} \tag{2}$$

Where, $G_{p1}(S)$ is the transfer function of the level loop (primary control objective) and $G_{p2}(S)$ is the transfer function of the flow loop (secondary control objective).

## 3. Fractional Order Based Cascade Controller Design

The general structure of a cascade control system is shown in Figure 3. The cascade control system consists of two loops: the inner secondary loop and outer primary loop. The proportional controller is used as secondary controller and PI controller is used as primary controller. The primary controller is replaced with fractional order PI controller[21-23] and the tuning of these controllers is discussed as follows.

The secondary loop with proportional controller is tuned using process reaction curve method. The primary controller i.e. integer order proportional plus integral (IO-PI) along with secondary loop is tuned using Z-N technique and the controller parameters are given in Table 1.

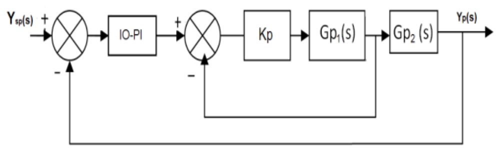


**Figure 3.** General block diagram of cascade control system.

**Table1.** Controller Parameter Values

| Controller | Parameter values | | | |
|---|---|---|---|---|
| | Inner secondary loop | Outer primary loop | | |
| | $Kp_1$ | $Kp_2$ | $Ki_2$ | $\lambda$ |
| IO-PI | 0.57 | 19 | 0.3 | - |
| FOPI | 0.57 | 21.2 | 0.22 | 0.55 |

### 3.1 FO-PI Controller Design

The primary loop integer order controller is replaced with fractional order PI controller. The fractional PI controller transfer function $G_c(s)$ is given as

$$G_C(s) = K_p + \frac{K_i}{s^{\lambda}} \tag{3}$$

Where, $K_p$ is the proportional gain, $K_i$ is the integral gain and λ is the fractional order of integrator. For a fractional order PI controller three parameters need to be tuned $K_p$, $K_i$ and λ. Hence, here in this paper genetic algorithm optimization technique is used to tune the parameters. The minimization of integral absolute error is considered as the controller tuning objective function.

The block diagram of cascade control system using genetic algorithm is shown in Figure 4.

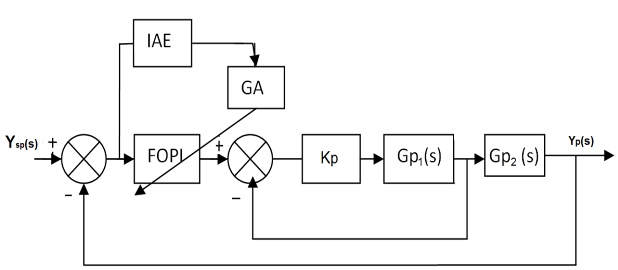


**Figure 4.** Block Diagram of FOPI Cascade Control System Tuned Using Genetic Algorithm.

### 3.2 FO-PI Tuning using Genetic Algorithm

The Genetic Algorithm[24] is a well known evolutionary optimization algorithm based on genetics and natural selection. It is an efficient algorithm compared to other optimization algorithm techniques.

The algorithm of genetic algorithm is as follows:

**Step-1**: An initial population of string is chosen randomly. If we know approximately where the minimal point for a function lies, we can set the initial range so that the point lies near the middle of that range.
**Step-2**: The fitness for each string is calculated. The fitness is the objective function written to obtain the optimal solution for the control problem.
**Step-3**: While an acceptable solution is not found.

- Repeat the reproduction process for next generation.
- Perform crossover between parents to create new off-spring, apply mutation and
- Calculate the fitness function of each offspring. End while

The design control problem is to find the best possible controller parameters, namely $K_p$, $K_i$ and λ that satisfy the objective function. The objective function is to minimize IAE (Integral Absolute Error) represented as, J.

$$J= \min\left(\int |e(t)|dt\right);$$

Where, $e(t) = Y_{sp}(s)-Y_p(s)$;
e(t) is the error signal that is given as input to the controller
$Y_{sp}(s)$ is the setpoint to the process
$Y_p(s)$ is the Process output
And the initial ranges is set to $10<K_p<40$; $0<K_i<2$; $0.5<\lambda<1.5$

From the knowledge of tuning parameter obtained using Z-N method. The optimal FO-PI controller parameter values are tabulated in Table 1.

## 4. Simulation Results and Discussions

The set point tracking of the proposed controller is compared with IO-PI controller. Figure 5 shows process output for change in set point operated with the desired value set at 15cm, 10cm, 20cm and 7cm at an interval of 1000 seconds. It is evident from the response that the FO-PI controller tracks the set point at a faster rate.

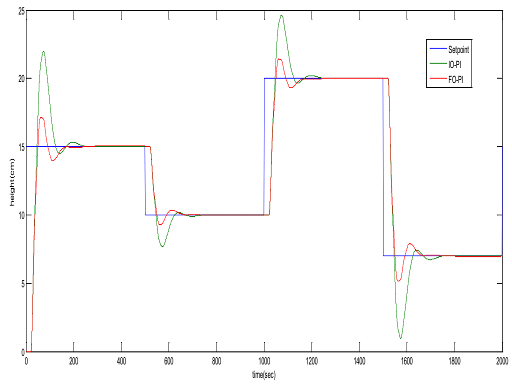


**Figure 5.** Servo response of the process.

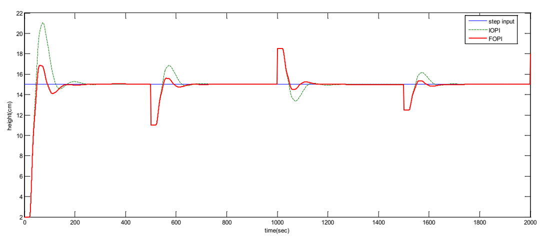


**Figure 6.** Regulatory response of the process.

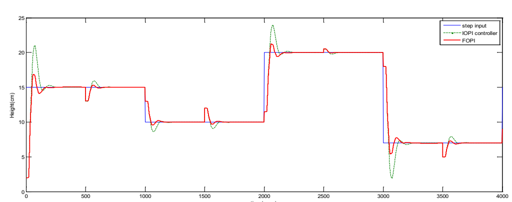

**Figure 7.** Servo-regulatory response of the process.

The regulatory response of the process is shown in Figure 6. The disturbance is applied at every 500 seconds. From the response it is clear that the FOPI controller is faster in rejecting the disturbances. Figure 7 shows the servo regulatory response of the process. The set point change is given at every 1000 seconds and disturbance applied at every 500 seconds.

From the response, it is clear that the designed controller can able to track the set point and reject the disturbances effectively than the IO-PI controller. The performance indices of IO-PI controller and FO-PI controller are compared and tabulated in Table 2.

**Table 2.** Comparison of performance indices of IO-PI & FO-PI controller

| Controller | Performance indices | | | |
|---|---|---|---|---|
| | Peak time (secs) | Rise time (secs) | Settling time (secs) | IAE |
| IO-PI | 74.5 | 47.5 | 235 | 845 |
| FOPI | 60.2 | 45.6 | 170 | 662 |

## 5. Conclusion

In this paper, genetic algorithm based fractional order PI controller is designed for a cascade control system. The PI controller parameters are obtained using Z-N method which is used as initial range for the proposed controller. The conventional PI controller performance has been improved by an additional parameter λ. The proposed controller is compared with conventional IO-PI controller in terms of peak time, rise time and settling time. The fractional order PI controller has faster settling time with minimum peak overshoot. From the simulation results it is evident that the designed FOPI controller works effectively.

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