IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321- 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 6, Issue 1, January 2018

Fractional Order IMC-PID Controller Design for Non-Linear System

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Abstract: This paper deals with the controlling of the non-linear system using fractional order IMC-PID controller. The IMC-PID controller does good set-point tracking but poor disturbance response essentially for the process which has a minute time-delay/time-constant ratio. The study of different methods of IMC design and IMC based PID controller has been intended for a plant transfer function to include the advantages of PID controller in IMC. The intended of fractional order $PI^{\lambda}D^{\mu}$ controller in which the orders of the Integral (I) and Derivative (D) parts λ and μ are fractional. The purpose of introduction of these two parameters is to ensure the robust performance of the system. The IMC is used to handle non-integer system with time delay. IMC PID controller has been designed for a plant transfer function to incorporate the advantages of PID controller in IMC. In order to reduce the number of tuning parameters and effects of time delay, the fractional order internal model control scheme is used.

Keywords: Fractional order, IMC, PID, Non-linear system, time delay.

I. INTRODUCTION

Nonlinear systems like spherical tanks find wide applications in gas plants and petrochemical industries. They are preferred because of the advantages like better disposal of solids, easy mixing and complete drainage of solvents such as viscous liquids in industries. In spherical tank non-linearity exists due to its variation in cross-sectional area [3]. Because of the non-linearity, level control is a challenging task in spherical tank and it demands for implementation in real time. The non-linear system faces the problem of overflow because the system cannot detect whether the water level has properly reached the desired level or the flow- in rate of the water is not proportional with the flow out rate. The implementation of the Fractional order Internal Model Control in water tank level control system can be used to overcome this problem. By doing some modifications the problem can be solved by using cheapest and simplest possible controller for a given application. The basic idea is still the same and the modification will be made depending upon the design expectation [4]. One interesting feature of this water tank system is that the tank empties much more slowly than it fills up because of the specific value of the outflow diameter pipe. By testing the system in this simulation area, the expected output from the input can be set earlier based on the rules set. Using DAQ card is significant in order to integrate the software and hardware parts of the system.

II. LITERATURE SURVEY

Dazi Li , Lang Liu, Qibing Jin, Kotaro Hirasawa (2015) proposed the method for a fractional order PID controller based on internal model control(IMC).Internal model control (IMC) is proposed to handle non-integer order systems with time delay. In order to reduce the number of tuning parameters and mitigate the impact of time delay, the fractional order internal model control scheme is used. They can be used not only fractional time-delay system but also in higher order systems [1].

Hadi Malek, Ying Luo, Yang Quan Chen (2013) has intended the model with a single fractional pole replacing the integer order pole. They proposed time delayed system model with a fractional pole as the starting point, fractional order controllers design for this class of fractional order systems is examined. Integer order PID and fractional order PI and [PI] controllers are intended and compared for these class of systems. The simulation comparison between PID controller and fractional order PI and [PI] controllers illustrate the advantages of the properly designed fractional order controllers [12].

Saptarshi Das , Suman Saha , Shantanu Das , Amitava Gupta (2011) proposed a comparative study on the time and frequency domain tuning approaches for fractional order (FO) PID controllers to handle higher order processes. A new fractional order template is used for reducing parameter modeling of stable minimum/non-minimum phase higher

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order processes is established and its advantage in frequency domain tuning of FOPID controllers is also presented and highlighted on the practical control system achievement issues like ease of online auto-tuning, condensed control signal and actuator size, capability of measurement noise filtration, load disturbance suppression, robustness against parameter uncertainties. s

Majid Zamani, Masoud Karimi-Ghartemani, Sadati, Mostafa Parniani (2009) has made Comparison with a PID controller and it is shown that the proposed FOPID controller can highly improve the system robustness with respect to model uncertainties. PSO algorithm is an advanced search procedure that has proved to have very high efficiency [2].

Concepcion A. Monje, Blas M. Vinagre, Vicente Feliu, Yang Quan Chen(2008) proposed the design of fractional order PI λDμ controllers, in which the orders of the integral and derivative parts, lambda(λ) and miu(μ), correspondingly, are fractional. The reason is to take advantage of the introduction of these two parameters and fully additional specifications of design, they ensuring a robust performance of the controlled system with respect to gain variations and noise. A process for tuning the PI λDμ controller is proposed in this paper with five different design specifications [15].

III. PROPOSED SYSTEM

A. PROCESS DESCRIPTION

The proposed system consists of a spherical tank and the reservoir. The 3Φ pump with Variable Frequency Drive (VFD) pumps the water through the upstream to the spherical tank and there is a Pressure Relief Valve (PRV) to avoid damage to the pump in no load conditions. In the upstream flow measuring elements Rotameter and Orifice meter with differential pressure transmitter are used for flow measurement. The flow rate can also be controlled by adjusting the input frequency of the pump through the VFD. Pneumatic Control Valve and Hand Valves are used as actuating elements to control the flow [7].

Fig.1 Experimental setup

The pneumatic control valve is air to open and manipulates the flow of the liquid pumped into the spherical tank from the liquid reservoir. The level of the liquid in the tank is measured by means of the Differential Level Transmitter. In the downstream the flow is controlled by another pneumatic Control Valve and Hand Valve. An electro pneumatic converter (I/P Converter) provides necessary pneumatic signals to actuate the control valves. Fig 1 shows the real time experimental setup of a spherical tank.

ISSN (Online) 2321-2004
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B. SPECIFICATIONS OF THE SPHERICAL TANK

PARTS/FIELD INSTRUMENTS	DESCRIPTION
Spherical Tank	Material: Stainless Steel, Diameter: 43 cm, (LRV= 436.5 mmH_2O, URV=866.5 mmH_2O, Volume: 42 liters
Pump and VFD	VFD: ABB-ACS350, 3Φ 4- 20 mA to 0 to 50 Hz. Pump: Grundfos-JP5 centrifugal pump, 3Φ.
DPT for level measurement (LT)	2600aT Series, Range:0 to 6500 mmH_2O, Output: 4 to 20mA+HART
DPT for level measurement (FT)	
Control valves	Linear, Air to open, Body:1”, Trim1/2”
Rotameter	150 to 1500 lph
I/P converter	Input:4 - 20 mA, 20 psi Output: 3 to 15 psi

C. MATHEMATICAL MODEL FOR CONICAL TANK SYSTEM

The Spherical tank system exhibits non-linear behavior due to variation on its shape. The layout of the system is shown in the Fig 2.

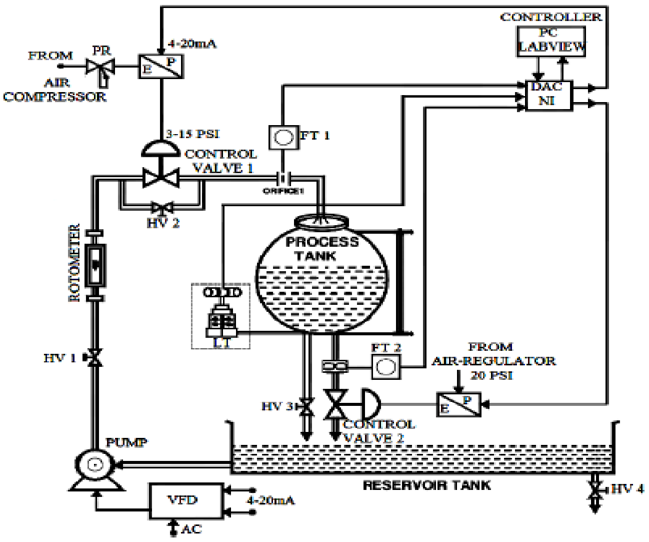

Fig.2 Layout of the system

The spherical tank in Fig.3 is fundamentally a system with nonlinear dynamics. The nonlinear dynamics illustrated by first-order differential equation.

$= F_{in}-F_{out}$ … (1)

Where V is the volume of the tank, Fin is the inlet flow and Fout is the output flow.

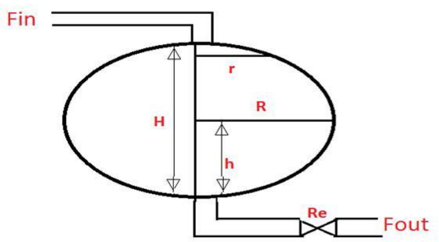

Fig.3 Schematic Diagram of Spherical Tank

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Volume of sphere (V) = πR^3 … (2)

Area of sphere (A) = $4\pi R^2$ … (3)

V= [AR] = [Ah]

Differentiating with respect to time (t)

= [A + h] … (4)

From the diagram =

Area (A) = $4\pi (r)^2$

Differentiating with respect to time (t)

= $8\pi ( )^2 h$ … (5)

Substitute 5 in 4

= [A + $8\pi () h^2$]

= [A+8π ($h)^2$

= [A+$8\pi R^2$] (=)

= [A + 2A]

= A (Mass balance equation) … (5)

$F_{in} – F_{out}$ = A

F_{out} = =

F_{in} = A +

Taking Laplace transform

F_{in} (S) Re H(S) S + H(S)

=

= … (7) (K= Re, τ = ARe)

= (τd = time delay)

D. LEVEL CONTROL OF SPHERICAL TANK SYSTEM

The level of spherical tank is measured by using Differential Pressure type Level Transmitter. The Level Transmitter output is taken as a process variable and the inflow/ outflow to the tank is manipulated using control valves [8]. The set point to the controller establishes the desired level. In this system, upstream and downstream load changes affect the level. The flow loop is a single variable system, but the point is determined by a measurement of level upstream load changes of the tank because the flow control system regulates such as before they appear as substantial changes in level. The level could be controlled by using two ways as follows

A. IN-FLOW CONTROL:

The inflow can be controlled by including the inflow control valve in the upstream by closing the hand valve. At the same time the outflow drain valve is opened so that the outflow control valve in the downstream is excluded in the control. The inflow can also be controlled by providing 4 to 20 mA signal to the Variable Frequency Drive (VFD) to alter the pump motor speed. The bypass valve and drain valve are kept open so that the inflow control valve and outflow control valve are excluded from control

B. OUT-FLOW CONTROL

The bypass valve is opened so that the inflow control valve is excluded from the control loop. At the same instant drain valve is closed so that the outflow control valve of downstream is included in the control loop [10]. A fixed current from current source is given to I/P of control valve to operate it. The speed of the pump motor is maintained constant throughout the process.

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IV. OPEN LOOP TEST

The open loop response is plotted and the values obtained from plot like percentage change in level (Q%),

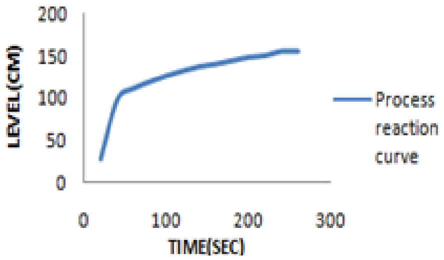

Fig.4 Open Loop test

delay time (t_d), the time taken by the level is used for getting mathematical model of the spherical tank Fig.4 shows the open loop test.

The First Order Process with Time Delay (FOPTD) model

Time constant =960seconds

G(s) indicated above is the obtained mathematical model for the entire operating range of spherical tank system.

A. PID GAINS FOR THE SYSTEM

Proportional gain,

)

$K_c = 0.91186$

Integral gain,

= 0.01865

Derivative gain,

V. FRACTIONAL ORDER IMC-PID CONTROL

The capabilities of proportional-integral (PI) and Proportional-Integral-Derivative (PID) controllers and that the controllers of an objective have led to their widespread receiving in the control industry. It is because, for practical applications or an actual process in industries PID controller algorithm is ease and robust to handle the model inaccuracies [12]. This error becomes rigorous for the process with time delay. For this I use transfer function with time delay. Fig.5 shows the schematic diagram of FOIMC process.

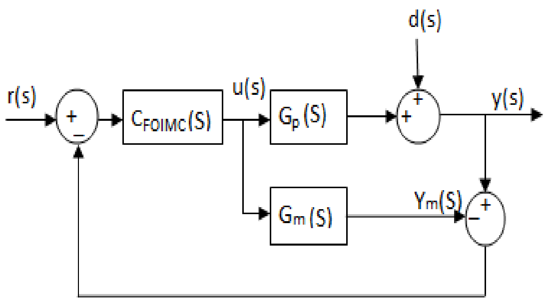

Fig.5 Schematic diagram for FOIMC Process

VI. INTERNAL MODEL CONTROL

The IMC design procedure) understand by IMC STRUCTURE Fig.6 is the “Internal Model Control” or “Q-parameterization” structure. It consists of an internal model p(s) and an IMC controller q(s) [11].

DOI 10.17148/IJIREEICE/611

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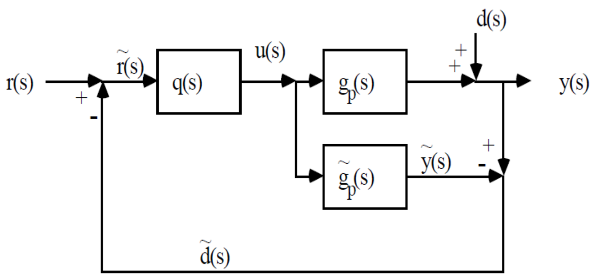

Fig.6 IMC Structure

For fast response and good robustness the tuning parameter is given by equation.

VII. RESULTS AND DISCUSSIONS

Response of the level controller using PID controller and Internal Model Controller based PID controller is as shown in the Fig.7

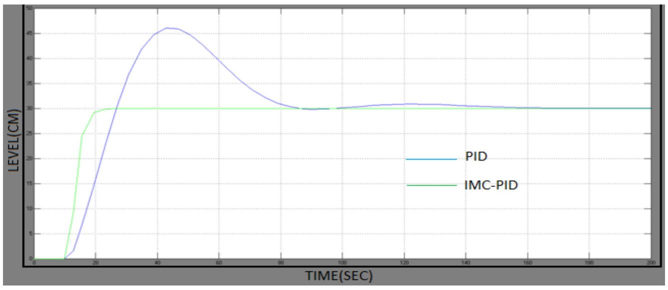

Fig.7 Simulink graph model for PID controller and Internal model Control

A Simulink model for PID controller, Internal model Controller based PID controller and Fractional order Internal model controller based PID controller for level control is as shown in the Fig.8

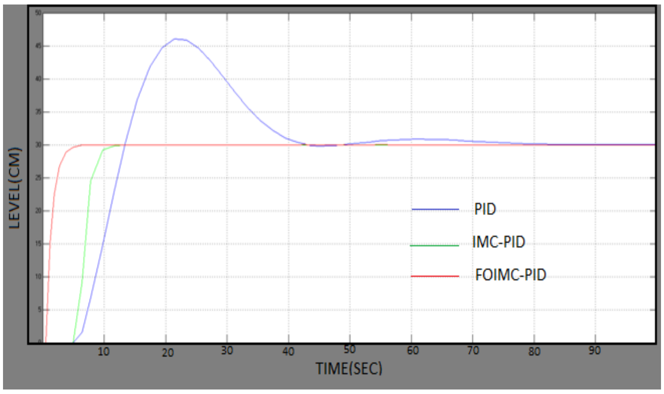

Fig.8 Simulink graph model for PID controller, Internal model Controller based PID controller and Fractional order Internal model controller based PID controller

VIII. CONCLUSION

The simulation result shows the IMC based PID controllers and fraction order IMC based PID controller. The standard IMC filter results in good set point response performances. The Fractional order IMC-PID controllers achieve better performance by tuning factor λ (lambda). Thus, by the best filter structure is the filter that gives the better PID performance for the optimum λ value. In which FOIMC-PID controller have minimum settling time and rise time in order to reach steady state value.

Future Scope

The future scope is to analyze the process reaction curve method using system identification tool in MATLAB and to implement the Fractional order IMC-PID controller in the real time non-linear process.

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