VOL. 10, NO. 8, MAY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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REAL TIME IMPLEMENTATION OF CONTROL STRATEGIES FOR THREE TANK PROCESS

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ABSTRACT

In this study the controller for three tank multi loop system is designed using coefficient Diagram method. Coefficient Diagram Method is one of the polynomial methods in control design. The controller design by CDM method is based on the choice of coefficients of the characteristics polynomial of the closed loop system according to the convenient performance such as equivalent time constant, stability indices and stability limit. Controller is designed for the three tank system by using CDM method. CDM-PI is compared with fuzzy gain scheduling and conventional PI controller .The proposed CDM design is fairly stable and robust whilst giving the desired time domain system performance.The real timeimplementation of these two control schemes is done using VDPID data acquisition module for the three tank process.

Keywords: coefficient diagram method, three tank, multiloop, CDM-PI, fuzzy gain scheduling.

1. INTRODUCTION

Many processes in refinery process, power plants, aircrafts and chemical industries are multivariable or multi-input multi-output (MIMO) and control of these MIMO processes are more complicated than SISO processes. The methodology used to design a controller for the SISO process cannot be applied for MIMO process because of the interaction exhibit between the loops. Usually two types of control schemes are available to control MIMO processes. The first is decentralized control scheme or multiloop control scheme, where single loop controllers are used (the controller matrix is a diagonal one). The second scheme is a [3] full multivariable controller known as the centralized controller and matrix is not a diagonal one. Multi loop controllers do not explicitly consider the decoupling of the inter-loop interactions unlike full multivariable controllers. In this paper, the Coefficient Diagram Method (CDM) is used to design a controller for MIMO process. CDM is now a well established approach to design controllers that provide outstanding time domain characteristics in closed loop system. Basically CDM is based on pole assignment, where the locations of the closed-loop system are obtained using predetermined templates. Although it has been demonstrated that the designs based on CDM has some robustness, it is possible to show that some of the nice characteristics of the design can be lost if large perturbations in the model of the system exists.The design of controller is not a difficult except the robustness issue, if the denominator and numerator of the transfer functions of the system are determined independently according to stability and response requirements. The CDM design procedure is quiet easily understandable, efficient and useful. Therefore, the coefficients of the CDM controller polynomials which can be determined more easily than the PID controller strategies. The CDM design procedure is possible to design very good controllers with less effort and easy when compared with the other method, under the conditions of stability, time domain performance and robustness. The transfer function of the numerator and denominator of the system are obtained independently according to stability and response requirements.. Generally the order of the controller designed by CDM is lower than the order of the plant. when using the PI controller for the first order plant, the order of the controller is equal to the order of the plant, and for the second order plant, the order of the controller is lower than the order of the plant equal to one .The parameters are stability index γi equivalent time constant and stability limit γi^* which represent the desired performance. The basic block diagram of the CDM design for a single-input-single-output system is shown in Figure-1.Where y is the outputsignal, r is the reference signal, u is the controller signal and d is the external disturbance signal N(s) and D(s) are to be numerator and Denominator of the plant transfer function. A(s) is the denominator polynomial of the controller transfer function, F(s) and B(s) are called the reference numerator and the feedback numerator polynomials of the controller transfer function. The CDM controller structure they are similar to each other. It has Two Degree of Freedom (2DOF) control structure because of two numerators in controller transfer function. The system output is given by

$$y(s) = \frac{N(s)F(s)}{P(s)} r + \frac{A(s)N(s)}{P(s)} d \quad (1)$$

Where P(s) is the characteristics polynomial of the closed loop system.

$$P(s) = A(s)\, D(s) + B(s)\, N(s) = \sum_{i=0}^{n} a_i s^i \quad (2)$$

CDM needs some design parameters with respect to the characteristic polynomial coefficient which are τ equivalent time constant γ_i stability index, and γ_i^* stability limit. The relations between these parameters and the coefficients of the characteristic polynomial (a_i) are shown in (3).

$$\tau = \frac{a_1}{a_0} \quad (3a)$$

$$\gamma_i = \frac{a_i^2}{a_{i+1}a_{i-1}}, i = 1 \sim (n-1), \gamma_0 = \gamma_n \quad (3b)$$

$$\gamma_i^* = \frac{1}{\gamma-1} + \frac{1}{\gamma+1} \quad (3c)$$

From equation 3(a) to 3(c), the coefficients a_i can be written as

$$a_i = \frac{\tau^i}{\prod_{j=1}^{i-1}\gamma_{i-j}^{j}} a_0 = Z_i a_0 \quad (4)$$

The design parameters are substituted in equation (2) and the target characteristic polynomial is obtained as

$$P_{target(s)} = a_0 \left[\left\{ \sum_{i=2}^{n} \left(\prod_{j=1}^{i-1} \frac{1}{\gamma_{i-j}^{j}} \right) (\tau s)^i \right\} + \tau s + 1 \right] \quad (5)$$

The equivalent time constant specifies the time response speed. The stability indices and the stability limit indices affect the stability and the time response. The variation of the stability indices due to plant parameter variation specifies the robustness.

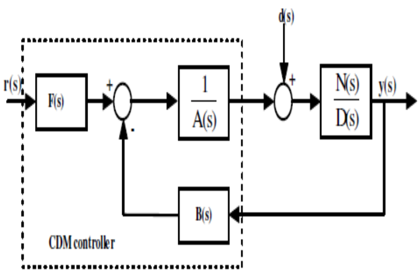

Figure-1. Standard block diagram of CDM.

2. CONTROLLER DESIGN USING CDM

Most of the processes encountered in industry are described as FOPTD

$$Gp\ (s) = \frac{Kp}{\tau_p s + 1} e^{-\theta s} \quad (6)$$

Where k_p is process gain τ is time constant and θ is time delay. Since the transfer function of the process is of two polynomials, one is numerator polynomial N(s) of degree m and other is the denominator polynomial D(s) of degree n where m≤ n, the CDM controller polynomial A(s) and B(s) of structure shown in Figure-1 are represented by

$$A\ (s) = \sum_{i=0}^{p} l_i s^i \text{ and } B(s) = \sum_{i=0}^{q} k_i s^i \quad (7)$$

For the controller to be realized the condition p ≥q must be satisfied. For a good performance the degree of controller polynomial chosen is important. The controller polynomial for FOPTD process with numerator Taylor's approximation is chosen as

$$A(s) = s \quad (8a)$$

$$B(s) = k_1 s + k_0 \quad (8b)$$

For computation of the coefficient of the controller polynomial in CDM technique, pole-placement method is used. A feedback controller is chosen by pole-placement technique and then, a feed forward controller is determined so as to match the steady-state gain of closed loop system. According to this, the controller polynomials which are determined by equation (8a) and (8b) are replaced in Equation (2). Hence, a polynomial depending on the parameters k_i and l_i is obtained. Then, a target characteristic polynomial $P_{target(s)}$is determined by placing the design parameters into Equation (5) which is known to be Diophantine equation.

$$A(s)\ D(s) + B(s)\ N(s) = P_{target}(s) \quad (9)$$

Solving these equations the controller coefficient for polynomial A(s) and B(s) is found .The numerator polynomial F(s) which is defined as pre-filter is chosen to be

$$F(s) = P(s)/N(s)\ |_{S=0} = P\ (0)/N\ (0) \quad (10)$$

This way, the value of the error that may occur in the steady-state response of the closed loop system is reduced to zero. Thus, F(s) is computed by

$$F(s) = P(s)/N(s)\ |_{S=0} = 1/k_p \quad (11)$$

2.1CDM-PI controller

The transfer function of conventional PI controller is

$$G_c(s) = kc(1+\frac{1}{Ti^s}) \quad (12)$$

The controller gain k_c and integral time Ti are related with polynomial coefficient as k_1=k_c and k_0=k_c/Ti. By using the CDM, the values of $k_1$and K_0 can be designed as follows:

1) Find the equivalent time constant τ
2) The stability index $\gamma_2 = 2$, $\gamma_1 = 2.5$ are used.

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3) From Equation (2), derive the characteristic polynomial with the PI controller stated in Equation (12) and equates to the characteristic polynomial obtained from Equation (14). Then the parameters $k_1$and K_0 of the PI controller are obtained.

3. EXPERIMENTAL THREE TANK PROCESS SETUP

The experimental setup contains a three tanks, water reservoir, pump, rotameter and Differential Pressure Transmitter (DPT), electro pneumatic converter called as current to Pressure (I/P) converter, interfacing module, and a Personal Computer (PC). The VDPID module supports two analog input channel and two analog output channel, and two pulse width modulation inputs. Its sampling time is 0.01 sec and baud rate is 38,400bytes per sec with 8-bit resolution. It is operating in the input voltage range from 0 volts to 5 volts and output ranges from 4to20mA of digital to analog converter. The block diagram of the three tank process setup is shown in Figure-3.

4) Set the pre-filter $B(s) = K_0$and $G_f(s)$ is feed forward controller

$$G_f(s) = \frac{F(s)}{B(s)} = \frac{k_0}{k_1 s+1} = \frac{1}{T_i s+1} \quad (13)$$

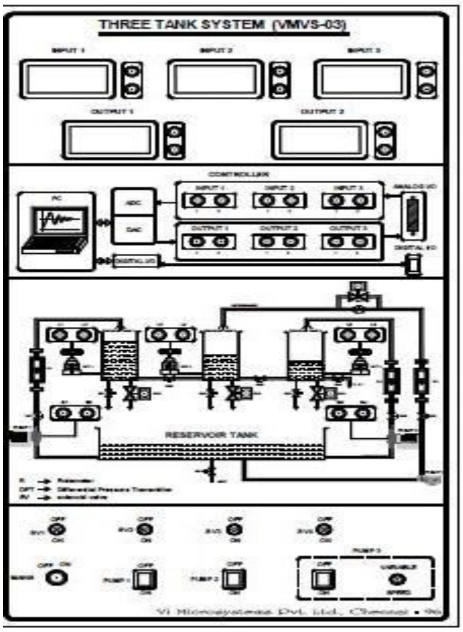

Figure-2. Experimental setup for liquid level Control of a three tank.

The three tank is made up of stainless steel and is mounted vertically on the stand. The water enters into the tank from the top and leaves to the reservoir, which is placed at the bottom of the tank. The level of the water in the three tank is quantified by means of the DPT. The quantified level of water in the form of current in the range of (4-20) mA is sent to the Current to Voltage (I/V) converter. The process variable in the form of analog voltage is transmitted to ADC module of the VDPID, which converts the analog data to digital data and feed it to the PC. The PC acts as the controller and data logger. The tank level considers the process variable and pump speed consider the manipulated variable. The DAC module of the VDPID converts this manipulated variable to analog form and transmit to the Voltage to Current (V/I) converter, which converts the analog voltage signal in the range of 0-5 volts to 4-20 mA current signal. The technical specifications of three tank process are given in Table-1.

4. SIMULATION RESULTS AND DISCUSSIONS

In the system identification of the three tank process using black box modelling, the loop is made open and level is maintained constant around a particular operating point [16]. Then, a small step change is given in the PC, which in turn reflects into the DAC module of VDPID interface card. As a result there is a change in level from operating point, which is observed by DPT and recorded in the PC through ADC module of VDPID interfacing card with the help of I/V converter. Thus for a step increment given in the input flow rate, various readings are recorded till the level in the three tank reaches a steady value. The open loop responses of the process by changing the manipulated variable from 50% to 60% level in tank1, the step decrement of manipulated variable from 60% to 50% level in tank1. Similarly step change inflows of tank3 manipulated variable from 40% to 50% level are plotted and the corresponding obtained responses are shown in from Figure-3 to Figure-6 respectively. The experimental data are approximated to a First Order plus Dead Time (FOPDT) model to obtain the open loop parameters of the three tank process.

Table-1. Technical specifications of experimental setup.

Part name	Details
Level transmitter	Piezo - electric with µC based built in sensor.
Rotameter	(50-500) Litre / Hour.
Pump	6500 Rpm and 230 VACS, 50Hz.
Process tank	Capacity15liter and Dimension 140 x 1000mm
Solenoid valve	Magnet Type and ½’’BSP(F) Thread
Orifice plate	Diameter3.5mm (4mm), Upstream distance 25 x D Downstream distance 5xD.
Thyristor power driver	Input signal (4-20)mA, Input Supply 230 V AC/50Hz and Output 0-230VAC 50Hz.

From the open loop response to obtain the parameters of the transfer function of the FOPDT model by letting the response of the actual system and that of the model to meet at two points, which describe the two

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parameters τ and θ. The proposed times, t_1 and t_2, are estimated from a step response curve on the 28.3% and 63.2% response times respectively. Based on the values of t_1 and t_2, the time constant τ is calculated as given in equation (14), and time delay td is calculated as given in equation (15). Another important parameter of the process model, the process gain K_p is calculated as given in equation (16).

$$\tau = 1.5(t2 - t1) \quad (14)$$

$$\theta = t2 - \tau \quad (15)$$

$$Kp = \frac{\text{Change in process output}}{\text{Change in process input}} \quad (16)$$

Table-2. Controller parameters for three tank process.

Types of controllers	Controller parameters			
	LOOP-1		LOOP-2	
	Kc1	Ti1	Kc2	Ti2
CDM-PI Controller	2.5230	156.75	2.3250	136.75
Z-N PIController	1.2342	140.75	0.9872	126.75

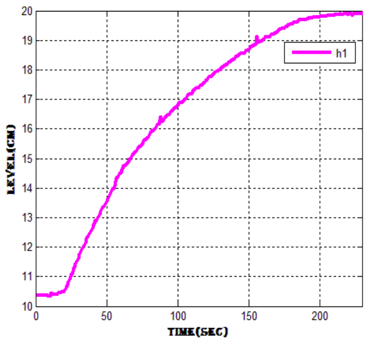

Figure-3. Open loop response of three Tank process in Tank1.

In this work, the coefficient diagram method based control system is considered for the three tank system under nominal operating conditions. The main objective of this process is to control the level of Tank1 and Tank3. The coefficient diagram method is designed based on the thorough knowledge of the three tank process. The controller parameters of three tank system are obtained by using Z-N method for the closed loop system. The closed loop response of CDM-PI controller for a set point change in tank1 from its operating value of 10.m to 15cm is shown in Figure-7 and its corresponding effect of interaction in tank3. Figure-8 shows the controller output for Tank-1 and Tank-3.Similarly positive and negative Step change in Tank-1 andTank-3 process output and controller output are shown in Figure-9 to Figure-18. Servo and Regulatory response of CDM-PI process and controller output for Tank-1 andTank-3 are shown in Figure 15 to16 and Figure16 to18 and their values are tabulated in Table-2. The simulated servo responses of Conventional-PI controller are stored in Figure-19 to Figure-25. The Servo and Regulatory response of Conventional-PI process and controller output for Tank-1 andTank-3 are shown in Figure 23 to25. The performance indices are calculated in terms of settling time, Integral Square Error (ISE) and Integral Absolute Error (IAE) and values are charted in Table-2.The closed loop response of Fuzzy-PI controller for a set point change in tank1 from its operating value of 10.5cm to 15cm is shown in Figure-26 and its corresponding effect of interaction in tank3. Similarly positive and negative Step change in Tank-1 andTank-3 process output and controller output are shown in Figure-27to Figure-32servo and regulatory responses are plotted in Figure-31 to 32. The table, it is clearly indicates that the control augmented the control system is considerably reduced the effect of load disturbance in the process variable compared to the PI controller.

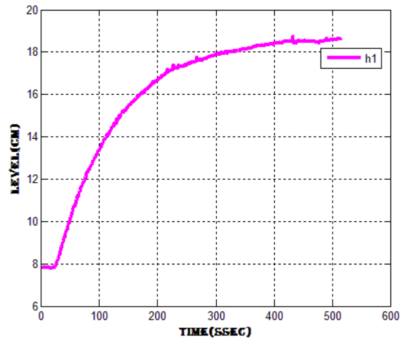

Figure-4. Open loop response of three Tank process in Tank3.

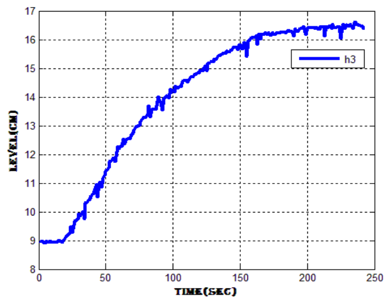

Figure-5. Open loop response of three tank Process in Tank3.

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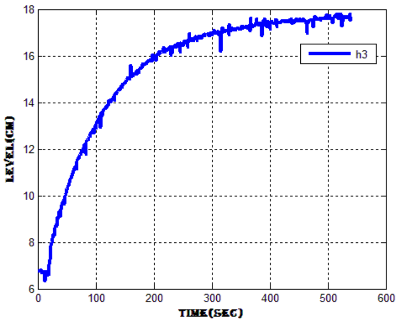

Figure-6. Open loop response of three Tank process in Tank3.

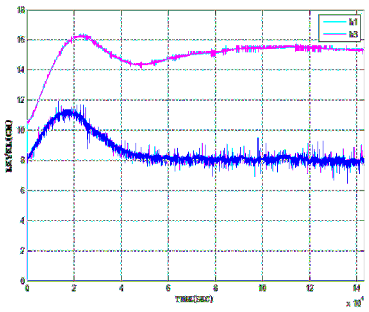

Figure-7. Closed loop response of three tank process with set Point change in Tank-1(CDM PI-Controller).

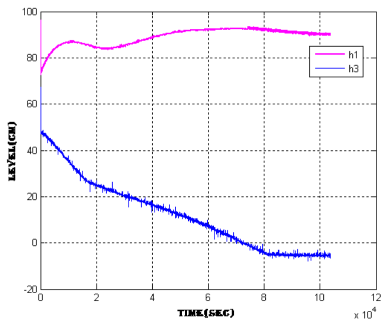

Figure-8. Controller output for Tank-1 and Tank3 (CDM PI-Controller).

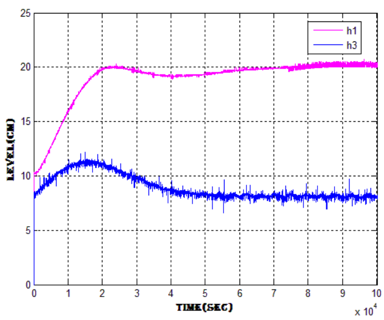

Figure-9. Closed loop response of three tank process with set point change in Tank-1(CDM PI-Controller).

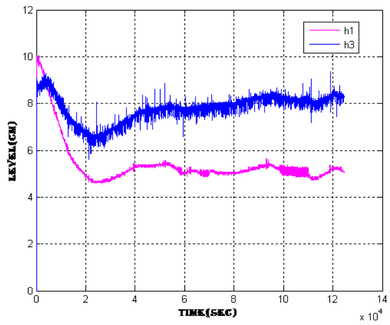

Figure-10. Closed loop response of three tank Process with set point change in Tank-1(CDM).

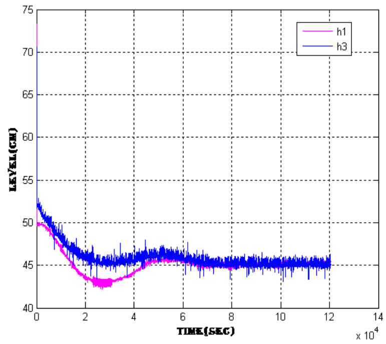

Figure-11. Controller output for Tank-1 and Tank3 (CDM PI-Controller).

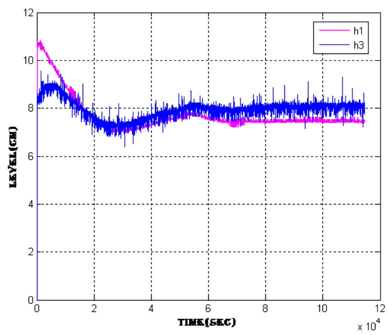

Figure-12. Closed loop response of three tank process with set point change in tank-1(CDM-PI) Controller.

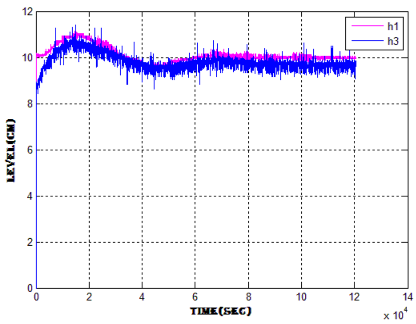

Figure-13. Closed loop response of three tank process with set point change in tank-3(CDM-PI) Controller.

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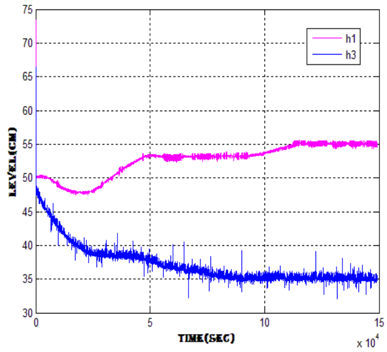

Figure-14. Controller output for Tank-1 and Tank3 (CDM PI-Controller).

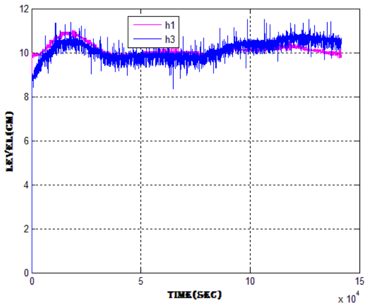

Figure-15. Closed loop response of three tank process with set point change in Tank-3(CDM-PI).

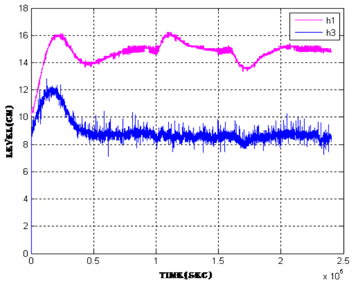

Figure-16. Servo and regulatory response of three tank process in Tank-1(CDM-PI) Controller.

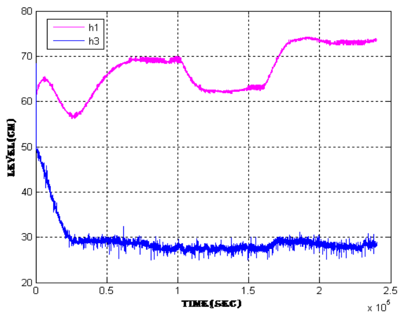

Figure-17 . Controller output for Tank-1 and Tank-3(CDM PI-Controller).

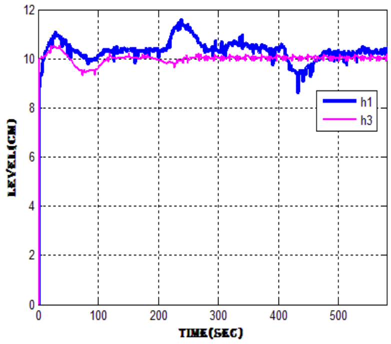

Figure-18. Servo and regulatory response of three tank process in Tank-3(CDM-PI) Controller.

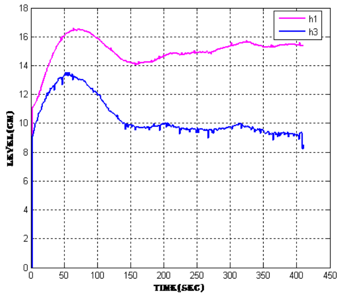

Figure-19. Closed loop response of three tank process with set point change in tank-3(Conventional -PI) Controller.

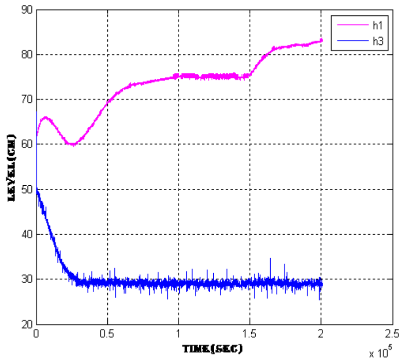

Figure-20. Controller output for Tank-1 and Tank-3 (Conventional PI-Controller).

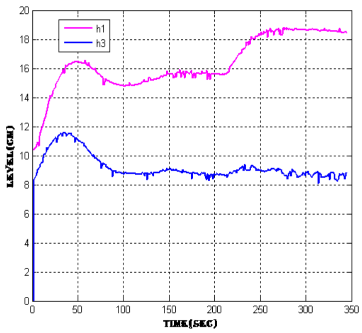

Figure-21. Closed loop response of three tank process with set point change in tank-1(Conventional-PI) Controller.

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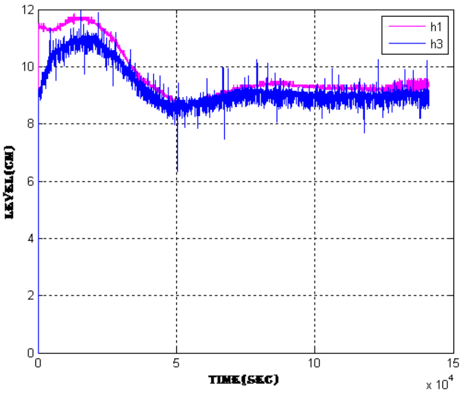

Figure-22. Closed loop response of three tank process with set point change in tank-1(Conventional-PI) Controller.

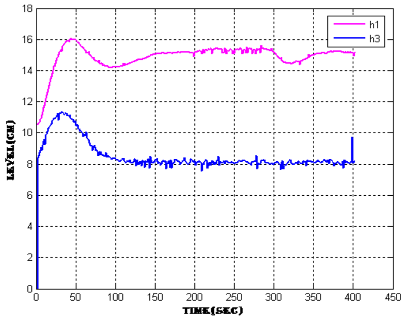

Figure-23. Servo and Regulatory response of three tank process in tank-1(Conventional-PI) Controller.

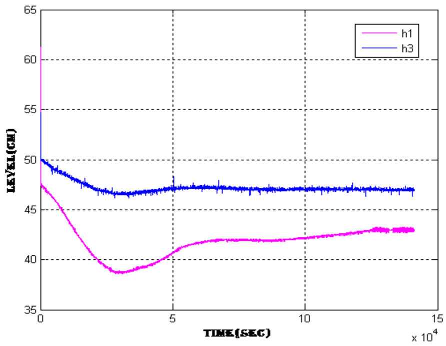

Figure-24. Controller output for Tank-1 and Tank-3 (Conventional PI-Controller).

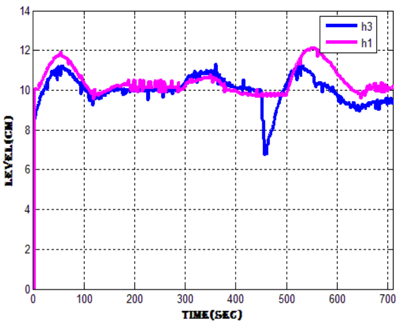

Figure-25. Servo and regulatory response of three tank process in Tank-3(Conventional -PI) Controller.

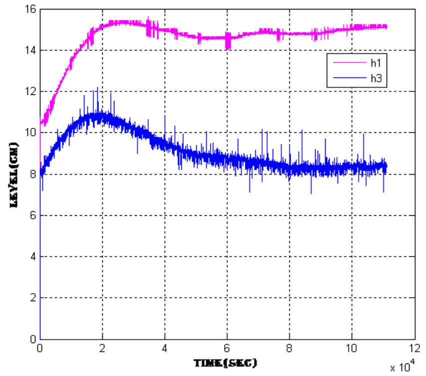

Figure-26. Servo response of three tank process in Tank-1(Fuzzy-PI) Controller.

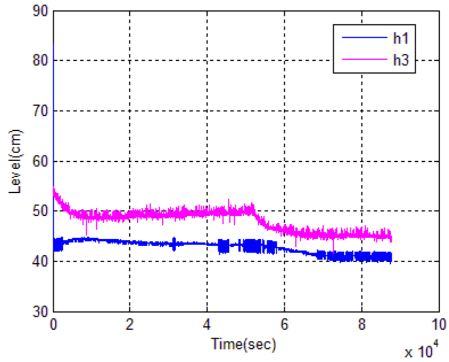

Figure-27. Controller output for Tank-1 and Tank-3 (FuzzyPI-Controller).

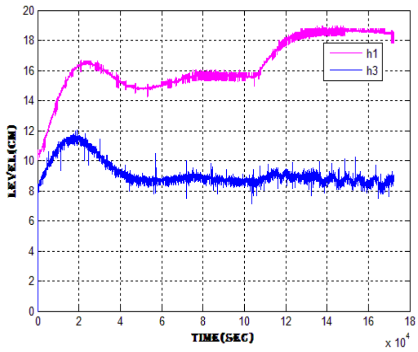

Figure-28. Servo response of three tank process InTank-1(Fuzzy-PI) Controller.

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Table-3. Performance and evaluation of the controller.

Controller scheme	Performance indices					
	Loop-1			Loop-2		
conventional PI controller	T_s	ISE	IAE	T_S	ISE	IAE
	350	1.4628e+005	2.6503e+004	398	6.1098e+005	4.7570e+004
CDM-PI Controller	260	1.2054e+004	1.1356e+005	165	2.8120e+004	2.4818e+004
Fuzzy PI controller	376	1.8863e+005	8.3210e+004	735	1.8021e+005	9.1778e+004

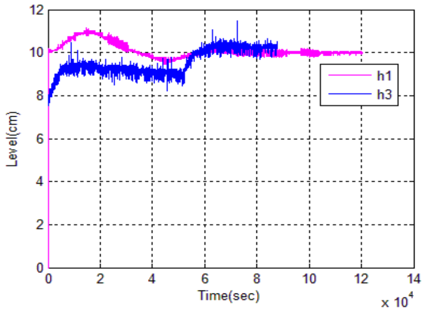

Figure-29. Closed loop response of three tank process with set point change in tank-3(Fuzzy-PI) Controller.

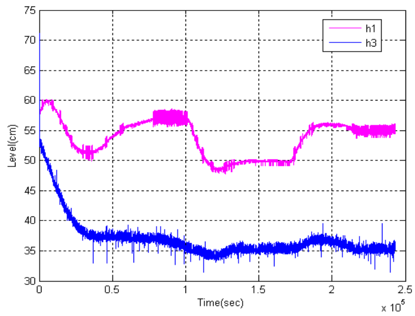

Figure-32. Controller output for Tank-1 and Tank-3 (FuzzyPI-Controller).

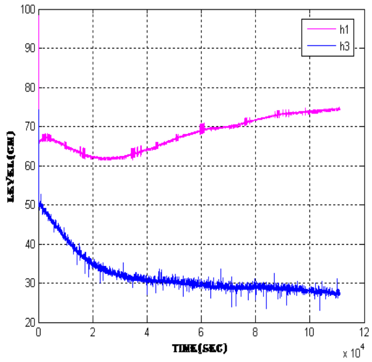

Figure-30. Controller output for Tank-1 and Tank-3 (FuzzyPI-Controller).

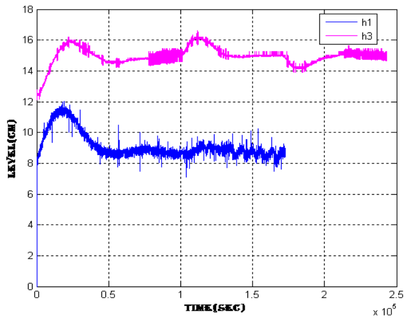

Figure-31. Servo and regulatory response of three Tank process in Tank-1(Fuzzy -PI) Controller.

4. CONCLUSIONS

In this proposed work, Multiloop CDM-PI controller is designed for three tank process and compared with the fuzzy PI and conventional-PI through Real time. The Ts, ISE and IAE are taken as performance indices. The superiority of the CDM-PI control is analysed and clearly shows that potential advantages of using CDM-PI control for a three tank process. The real time results reveal that proposed controllers have good set point tracking and load rejection at different operating point without any offset with reasonable settling time. The comparison of the present two controllers reveals that CDM-PI control is superior resulting in smoother controller output without oscillations which would increase the actuator life.

REFERENCES

[1] S.Abraham Lincon., D.Sivakumar., J.Prakash. 2007. State and Fault Parameter Estimation Applied To Three-Tank Bench Mark Relying On Augmented State KalmanFilter,ICGSTACSE Journal. 7(1).

[2] M.Zhaung and D.P. Atherton. 1994. PID controller design for TITO system. IEEP process controls Theory Appl. 141(2): 111-120.

[3] A. Niderlinski. 1971. A heuristic approach to the design of linear multivariable integrating control system Automatica. 7: 691-701.

[4] P.J. Cawthrop. 1987. Continuous-Time self-Tuning Control.Vol.1-Design, Research Studies Press, Letchworth, UK.

[5] Q.G. Wang, B. Zou, T.H. Lee and Q. Bi. 1996. Auto tuning of multivariable PID controllers from decentralized relay feedback.Automatica. 33(3): 49-55.

[6] S.Majhi. 2001. SISO controller for TITO systems.Presented at the Int. Can on Energy. Automation and information Tech.

[7] S.Skogestad, I.Postlehwaite. 1996. Multivariable Feedback Control Analysis and Design. John Wiley and Sons Chichester.

[8] S.Manbe. 1998. Coefficient Diagram Method. Proceedings of the 14thIFAC Symposium on Automatic Control in Aerospace, Seoul.

[9] K.Astrom and T. Hagglund. 1995. PID Controllers: Theory Design and Tuning. Instrument Society of America, 2ndEdition.

[10] I.Kaya. 1995. Auto tuning of a new PI-PD Smith predictor based on time domain specifications. ISA Transactions. 42(4): 559-575.

[11] S.Manabe. 1994. A low cost inverted pendulum system for control system education. Proc. of the 3rd IFAC Symp. On advances in control Education, Tokyo, Japan.

[12] A. Desbiens, A. Pomerlau and D. Hodouin. 1996. Frequency based tuning of SISO controllerfor two -by-two processes. IEE Proc. Control Theory Appl. 143: 49-55.

[13] M.Senthilkumar and S. Abraham Lincon. 2012. Design of stabilizing PI controller for coupled tank MIMO process. International Journal of Engineering Research and Development. 3(10): 47-55.

[14] S.E Hamamci, I. Kaya and M.Koksal. 2001. Improving performance for a class of processes using coefficient diagram method.Presented at the 9th Mediterran conference on control, Dubrovnik.

[15] S.E. Hamamci. 2004. Simple polynomial controller design by the coefficient diagram method. WSEAS Trans. on Circuits and Systems. 3(4): 951-956.

[16] S.E. Hamamci and M. Koksal. 2003. Robust controller design for TITO systems with Coefficient Diagram Method. CCA 2003 IEEE Conference on Control Applications.

[17] W.LLuyben. 1986. Simple methods for tuning SISO controllers in multivariable systems. Ind. Eng. Chem. Process Des. Dev.25 654-660.