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Real Time Implementation of Wiener Model PI (WMPI) Controller in a Conical Tank Liquid Level Process

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Abstract: Level control is very important for the successful operation of most chemical and biochemical industries since it is through the proper control of flows and levels that the desired production rates and inventories can be achieved. The aim of this study was the development and real time implementation of a Wiener Model based PI Controller (WMPIC) for a conical tank level process. The conical tank level process exhibits severe static non-linear behavior and dynamic characteristics. Here, a WMPIC structure was developed by the way of compensating the process static non-linearity. Tuning rules suggested by PadmaSree-Srinivas-Chidambaram (2004) and Ziegler-Nichols (1942) were considered here for designing the controller. The real time implementation results of wiener model based PI controller were compared with those obtained using a conventional Linear PI Controller (LPIC). The performance of these controllers was analyzed in terms of Integral Square Error (ISE) criterion. In addition to this, the robustness of the controllers was also analyzed.

Key words: Real time, wiener model pi, tuning rules, integral square error

INTRODUCTION

Interest in nonlinear feedback control of chemical processes has been steadily increasing over the last several years. This is due to both the pronounced nonlinear nature of several chemical processes (whether in mature or emerging fields) and to the increased sensing and computational capabilities afforded by modern sensors, computers, algorithms and software. Such capabilities have been claimed and at times proven to offer benefits in better operation and control of chemical processes. Linear controllers can yield a satisfactory performance if the process is operated close to a nominal steady state or is fairly linear. But the performance of the controller degrades with change in operating point and process parameters. Thus, there is an incentive to develop and implement nonlinear control strategies in chemical processes. A review was done by Bequette (1991). But the performance of these controllers showed some degradation if there are frequent disturbances in the process. In recent years there has been extensive interest in feedback control schemes that take the process non-linearity in control calculations. For these advances to be applied to systems in chemical process industry, it is necessary to develop nonlinear models that can be easily utilized by non-linear control schemes. The simple nonlinear model description, which takes in to account the gain variations is given by Hammerstein models (Chidambaram, 1998) (nonlinear gain in earlier portion), Wiener models(nonlinear gain in later portion) and combined Wiener and Hammerstein models. But empirical modeling, assuming some fictitious components and parameters defining their nature, is needed, which might not be accurate in all cases. In order to tackle severe non-linearities associated with the chemical processes, Wiener Model based controllers has been developed. Norquay *et al*. (1998) discussed a Wiener model based MPC strategy. They discussed the possible choices of linear dynamic element and non-linear static element. Patwardhan *et al*. (1998) discussed the implementation of input constrained, nonlinear MPC in latent spaces using Partial Least Square (PLS) based Hammerstein and Wiener models. But MPC requires an optimization problem to be solved at every sampling instant and practical implementation of MPC is difficult in comparison to PI and PID controllers. Arvind Kumar *et al*. (2004) made an attempt to implement Wiener model based PI controller for pH process to overcome nonlinearities In the present work an attempt is made for the real time implementation of the recently developed controller tuning rules

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(Padma Sree *et al.*, 2004) in Wiener Model based PI Controller (WMPIC) to the nonlinear chemical process. The nonlinear chemical process considered in this study, for the real time implementation of the tuning rules, include Conical Tank Liquid Level System (CTLLS).

CONTROLLER DESIGN TECHNIQUE

Ziegler-Nichols method (1942): The second method of ZN known as the process reaction curve method was proposed in 1942 to determine the PI parameters for the First Order Plus Time Delay (FOPTD) model. The PI parameters are calculated as: $Kc = 0.9 \times \tau/K \times \tau_d$; $\tau_i = 3.33 \times \tau_d$; The common disadvantage is that the resulting closed loop system is often more oscillatory than desirable.

Padmasree-Srinivas-Chidambaram method (2004): This method is proposed to design PI/PID controllers for stable first order plus time delay systems. It is based on matching the coefficient of corresponding powers of 's' in the numerator and that in the denominator of the closed transfer function for a servo problem. It gives simple equations for the controller setting in terms of FOPTD model parameters. PID controller settings are calculated as: $k_c \times k_p = (\tau/\tau_d) + 0.5$; $\tau_I = \tau + 0.5\ \tau_d$

$$\tau_D = (0.5\ \tau_d\ (\tau + 0.1667\ \tau_d))/(\tau + 0.5\ \tau_d)$$

Wiener model (Chidambaram, 1998): For non-linear system with significant variations, the controller design at one operating point usually shows unsatisfactory performance at the other operating points. The system with such significant variations in process gain can be represented by a Wiener model as shown in Fig. 1.

A Wiener model consists of a linear dynamic element followed in series by a non-linear static element. This static non-linearity can be effectively removed for the control problem. The choice of non linear static element ranges from simple algebraic equations to complex neural networks. The choice is governed by the fact that the model used for control purpose might have an inverse. Polynomial models are usually employed to represent the non linear because they have an inverse by their roots. Odd order polynomials are preferred since they have at least one real roots.

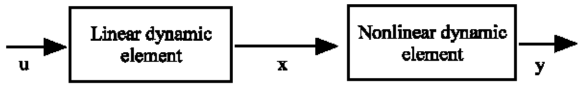

Fig. 1: Wiener model structure

EXPERIMENTS AND ANALYSIS

The setup consists of a mild steel conical column of 34 cm in diameter and slant height of 60 cm, opened to the atmosphere at the top. Flow rate is metered with rotameter at the inlet. A RF capacitance level sensor is used to measure the level in the tank (0-35cm). The output current signal (4-20 mA) from the sensor is processed using a VAD 104,a multifunction, high-speed Analog and Digital Converter (ADC) interface board, to digital value (ADC value). This digital value is read back as level and compared to the set point and the real time PI control algorithm written in C provides an appropriate control signal, which is again a digital value. This value is converted to an analog (4- 20 mA) signal in a digital to analog converter using VAD 104. The current signal is converted to a pneumatic signal in Watson-Smith, an I/P converter. This pneumatic signal control algorithm is implemented using a PC-P4, which is interfaced to the liquid level system. In open loop scheme, after the system reaches a steady state, a step magnitude of +10% DAC output to control valve is given. The level in the tank varies and this variation in level (through RF capacitance Sensor) is recorded against time until a new steady state is reached. This recorded data are converted into fractional response and plotted against time to obtain process reaction curve. From this reaction curve the model parameters are estimated (Sunderasan and Krishnaswamy, 1978). Similarly model parameters at different steady state values in the CTLLS are also identified.

Wiener Model based PI Controller Design Procedure [WMPIC]:

- From the experimental data, choose the worst case of model parameters (larger process gain, larger delay and smaller time constant of the process)
- Calculate PI controller settings based on the above selected model parameters using PSCTR (PadmaSree-Srinivas-Chidambaram Tuning Rules) and ZNTR (Ziegler-Nichols Tuning Rules).
- Identify the inverse of the static non-linearity element in process in order to remove the nonlinear behavior of the process from the control problem.
- Represent the identified inverse function as third order power series.
- Using the values obtained in step no: (2) and (4), developed a Wiener Model based PI Controller.

Based on the above steps the model parameters required for WMPIC structure in CTLLS are calculated and are tabulated in Table 1.

Table 1 Identified Model Parameters at different steady state points

Cases	K_p	Tau	Delay
36-46	1.88	85.76	16.41
38-48	1.51	76.38	12.39
42-52	1.66	111.89	33.89
46-56	1.00	80.94	34.66
50-60	1.42	56.95	23.32

Transfer function $G_{pw}(s) = 1.88 \exp(-34.66)/(56.95s + 1)$

Table 2: Controller parameters based on worst model parameters

TUR	Kc	Taui	Ki
PCTR	1.14	74.28	0.013
ZNTR	0.79	115.41	0.009

Worst case of model parameters are: Process gain, $K_p = 1.88$; Process delay, $D = 34.66$ s; Process time constant, $\tau = 56.95$ s

PI controller settings are tabulated in Table 2.

RESULTS AND DISCUSSION

A first order time delay (FOPTD) transfer function based model for the CTLLS is developed by performing a plant step test at different steady state points. Model parameters at different steady state points in CTLLS are identified (Sunderasan and Krishnaswamy, 1978) and the results are tabulated in Table 1. Worst case of model parameters of the process is chosen to develop WMPIC structure. Based on this model parameters of the system, the ZNTR controller settings and PSCTR controller settings are calculated and summarized in Table 2.

Figure 2 shows the inverse static nonlinear element (NL^{-1}). It is identified as $0.0396y^3 - 1.2831y^2 + 55.274y + 439.46$; where y is output of the process. $R^2 = 0.9582$. The servo responses at operating point 15.75 cm, for the two control systems, which are designated, by WMPIC using ZNTR and WMPIC using PSCTR, at different step sizes are shown in Fig. 3 and 4. These Figures 3 and 4 express the nominal performance characteristics of the WMPIC. The performances of the controller in terms of ISE are presented in Table 3.

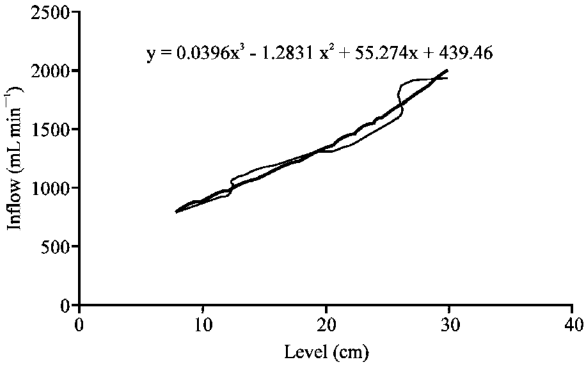

Fig. 2: Inverse of static non-linearity element in CTLLS

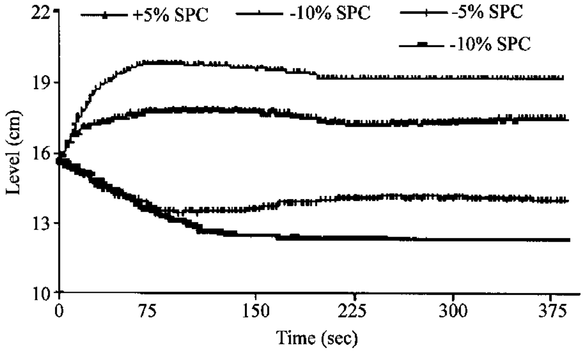

Fig. 3: Real time servo response of WMPIC using ZNTR for various step sizes at operating point of 15.75 cm

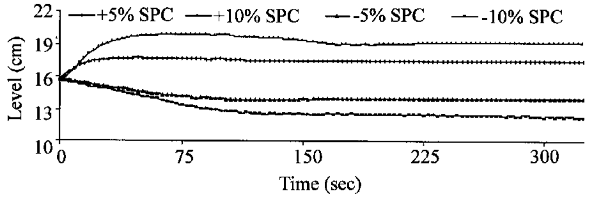

Fig. 4: Real time servo response of WMPIC using PSCTR for various step sizes at operating point of 15.75 cm

Table 3: WMPIC Performance criterion in ISE

Set Point Change (%)		ISE (cm) Rules	
[Operating Point:15.75cm]		ZNTR	PSCTR
SPC: Increasing Trend			
1	+05	15.02	7.93
2	+10	59.28	59.36
SPC: Decreasing Trend			
3	-05	20.69	29.45
4	-10	156.60	162.01

From Table 3 it is observed that PSCTR in WMPIC gives better result than ZNTR in WMPIC in the increasing trend of set point changes. At the same time it works very close to ZNTR in WMPIC in the decreasing trend. Figure 5 shows the servo response of LPIC using PSCTR for various step sizes at operating point of 15.75 cm. It is noticed from this Figure 5 that LPIC gives uniform oscillatory response throughout the operating time and also the process variable (level) never attains the constant new steady state value. The effect of load disturbance (increase of 43 mL/15 sec in load) is also analyzed in the WMPIC structure. Regulatory response for this load disturbance at operating point of 15.75 cm was recorded. Here again it was noticed that PSCTR in WMPIC takes quick action to nullify the load disturbance. Operating the

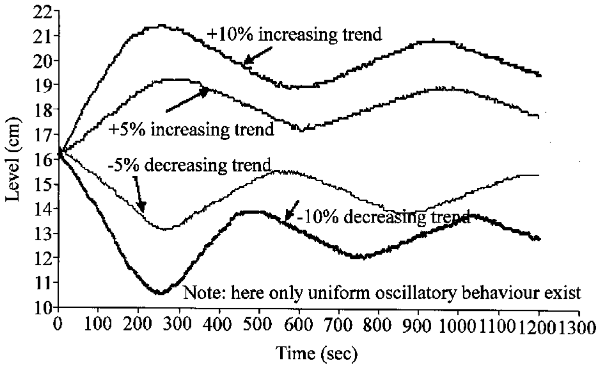

Fig. 5: Real time servo response of LPIC using PSCTR for various step sizes

Table 4: WMPIC Performance criterion in ISE

Set Point Change (%)		ISE (cm) Rules	
[Operating Point:17.5 cm]		ZNTR	PSCTR
SPC: Increasing trend			
1	+05	18.41	12.49
2	+10	67.18	56.69

process at another operating point of 17.5 cm checks the robustness of the WMPIC. The results show the better performance of WMPIC in this region (Table 4).

CONCLUSION

In this study, a Wiener Model based Control scheme was designed using two different tuning rules namely Ziegler-Nichols tuning rules (1942) and PadmaSree-Srinivas-Chidambaram tuning rules (2004). Real time implementation of this WMPIC is carried out in conical tank liquid level system. Performance of PSCTR in WMPIC is calculated in terms of ISE. Comparison of this performance with ZNTR in WMPIC was analyzed. It was observed that PSCTR in wiener Model based Control scheme gave fairly a good result in terms of ISE. The effect of load disturbance was also analyzed. In this case, PSCTR in WMPIC works better than ZNTR in WMPIC. Robustness of this WMPIC structure was tested with another operating point.

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