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Design of Controllers Based on the Identified Model for the Humidifying Pilot Plant

Sivanandam Venkatesh, K. Ramkumar and Rengarajan Amirtharajan
Department of Electronics and Instrumentation Engineering, SASTRA University,
Tirumalaisamudram, Thanjavur, 613 401, India

Abstract: Humidity control plays significant role in various industries to get desired product output. An experiment was conducted in the laboratory scale to model a humidity process and to control the same. Open loop test was conducted for the humidity process by introducing the step change and the relative humidity of the exit air was measured. The data was best matched with first order process with time delay. Proportional Integral (PI) controllers based on Ziegler Nichols (ZN), Direct Synthesis (DS) and Internal Model Control (IMC) methods were simulated in MATLAB environment and the time domain specifications showed better performance for IMC and DS based PI controllers.

Key words: Humidification, modeling, tuning, controllers

INTRODUCTION

Humidity is the term related with water vapor present in the gaseous mixture. The total amount of water vapor contained in the air is expressed as absolute humidity. The Relative Humidity (RH) is the term related to ratio of partial water vapor pressure to saturation water vapor pressure at the given temperature. Thus, RH is temperature dependent. The measurement is expressed as a percentage. The temperature and relative humidity both are dependent to each other. The relative humidity decreases with increase in temperature. Humidity is the most important parameter to be maintained in the industries such as pharmaceuticals, textiles, food processing and tobacco to achieve the desired product quality. Venkatesh and Sundaram (2012) have reviewed the effect of humidity on product quality and human comfort in various industrial processes as well as air conditioning systems and also different control schemes for maintaining the same. Young *et al*. (2007) concluded that formulation of dry powder inhaler and aerosolisation efficiency are affected if proper humidity level is mot maintained. Better performance in terms of time and quality in the preparation of photonic crystal films are achieved if desired RH level is maintained (Liau and Huang, 2008). Rao (1989) suggested that the lesser heat is recovered in power generation if humid air turbine is utilized.

Hence, it is essential for the industries as well as human comfort to control and maintain the relative humidity to the desired level. A good controller is needed to maintain the relative humidity to the desired value. The designed controller should be optimum in all aspects of performance. An independent control of humidity in Heating Ventilating and Air Conditioning system (HVAC) is proposed by Liu *et al*. (2006), which utilizes the combination of refrigerator and liquid desiccant system. A decoupled independent control of relative humidity and temperature is proposed by Gomez and Reyes (2001), which uses multivariable cascade control. The inner loop uses decoupling and the outer one uses PD controller. Han and Zhang (2011) reported the independent control of humidity and temperature for air conditioner. In this method, the sensible and latent heat loads are removed separately to maintain relative humidity and temperature so that indoor comfort and consumption of energy are improved. Soundaravalli *et al*. (2007) have proposed model based on control for the humidifying process with transportation lag. They designed different control schemes such as ZN, IMC, Smith predictor and IMC based PID for humidity process and tested for servo and regulator problems.

Model based controller for different processes have been addressed in the literature. Madhavasarma and Sundaram (2007, 2008) have identified the model for linear and non linear processes and different controllers were also designed. Vijaya Selvi *et al*. (2006) designed and implemented internal model controller based on identified model for a conductivity process with transportation lag. Ziegler and Nichols (1993) proposed a conventional

Corresponding Author: Sivanandam Venkatesh, Department of Electronics and Instrumentation Engineering, SASTRA University, Tirumalaisamudram, Thanjavur, 613 401, India

tuning technique for PI controller for stable first order process with dead time. Hagglund and Astrom (2008) suggested tuning rules for PI controller from step response. Chen and Seborg (2002) proposed direct substitution of formula for direct synthesis based PI/PID controller. Fruehauf *et al*. (1994) discussed IMC based PID tuning rules. Erdal ***et al.*** (2001) have developed a module for PID controller using current feedback amplifier with the help of active components.

Genetic algorithm based PID controller has been developed and implemented for a nonlinear plant (Ajlouni and Al-Hamouz, 2004) which resulted better integral squared error for set point changes for a particular operating point. Bhaba *et al*. (2007) studied Wiener model based PI controller for a conical tank process and compared with Ziegler and Nichols tuning strategy in terms of integral squared error. Ajlouni and Al-Hamouz (2004) proposed a neural based PID controller as well as feed forward controllers using evolutionary approach in genetic algorithm. Outperforming performance in time domain was achieved in this approach even in the presence of uncertainties in the plant parameter. Internal model controller was realized for induction motor to control the speed which uses artificial neural network to eliminate the sensor (Mouna and Lassaad, 2007).

After reviewing the existing methods, this study addresses the problem of identifying the black box model, for the humidifying pilot plant was performed and for the identified model, different controllers were designed and implemented.

HUMIDITY PROCESS AND SYSTEM IDENTIFICATION

A Humidity Chamber (HC) is present in the experimental setup which is shown in Fig. 1. The valve V1 is manipulated to bubble the primary air into the HC. The primary air flow rate is measured using the rotameter R. The humidified air at the outlet is made to pass through the coil of 1.25 cm long and 3 m diameter. HIH-3610 Honeywell made sensor is used to measure the relative humidity of the exit air. The air flow rate was adjusted in steps of 0.05 LPM from 0.35-0.6 LPM to achieve different operating regions. The step response was recorded for all the six operating regions. The next step input was given by manipulating the valve V1 after the steady state was reached. Process reaction curve as shown in Fig. 2 was obtained using the recorded data for six different operating regions. The process model was identified as suggested by Bequette (2003) from the process reaction curve. The identified model was validated against the experimental data with calculated data. The model was best fitted to a first order process with time delay with an accuracy of 5%. Table 1 shows the model parameters for six different operating regions.

DESIGN OF CONTROLLERS

Maintaining the relative humidity to a desired value for human comfort and product, quality is achieved by different control strategies. Lot of control techniques is available in literature for control of humidity and/or temperature. Proportional only controller leads to offset because the controller output and process output attain new equilibrium value. Hence the integral of error is taken into account and the past history of the process is considered (Nithya *et al*., 2008). So the controller output keeps on changing till the error becomes zero. In this study, several Proportional Integral control (PI) schemes are analyzed and simulated using MATLAB environment. The PI controller output is expressed as:

$$c(t) = k_c e(t) + k_I \int_0^t e(t)dt \quad (1)$$

Table 1: Model parameters identified for different operating regions

Operating regions (LPM)	Initial flow rate of air (LPM)	Gain (K)	Dead time (θ)	Time constant (τ)
0.35-0.4	0.35	319.2	14.5	720
0.4-0.45	0.40	293.2	12.7	680
0.45-0.5	0.45	195.4	11.3	650
0.5-0.55	0.50	123.8	10.2	480
0.55-0.6	0.55	122.8	9.24	470
0.6-0.65	0.60	71.6	8.48	385

LPM: Liters per minute

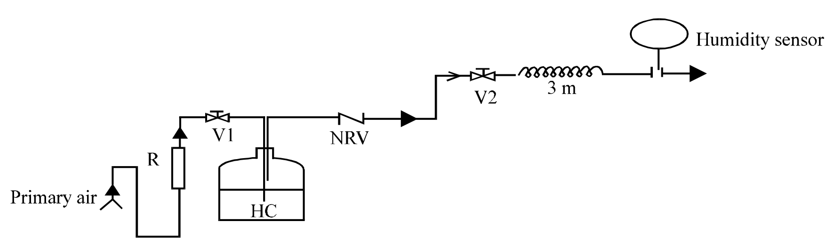

Fig. 1: Flow diagram of the experimental setup. HC: Humidity chamber, R: Rotameter, V1, V2: Manual valves and NRV: Non return valve

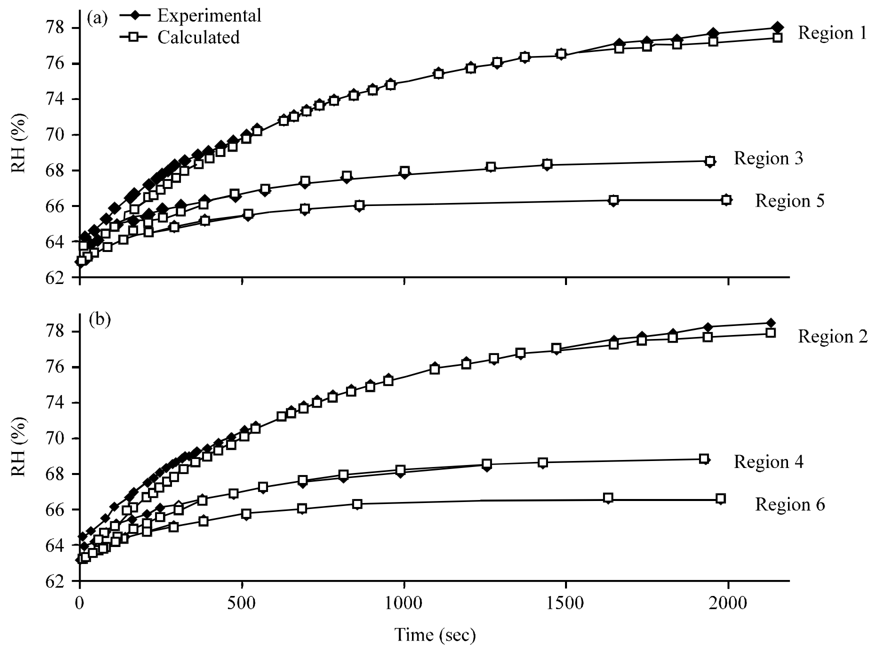

Fig. 2(a-b): Process reaction curve for system identification for different operating regions (a) 1, 3 and 5 and (b) 2, 4 and 6

The transfer function for the same is given as:

$$G_c(s) = k_c \frac{(\tau_I s + 1)}{\tau_I s} \quad (2)$$

PI controller tuning using ZN technique (ZNPI): Tuning of PI controller was suggested by Ziegler and Nichols which was a closed loop technique. The step response of the system was analyzed. After making the system response to sustained oscillation, the ultimate period and ultimate gain were determined. Direct substitution of the formula was also proposed by Ziegler and Nichols. From the frequency response plot also the ultimate gain and ultimate period may be found. The ZN tuning rules are suggested by Coughnwar and Leblanc (1991). The tuning values are determined by substituting the ultimate gain and ultimate period. The proportional term is obtained as K_c = 0.45 K_u and the integral term as $\tau_I = P_u/1.2$. Coefficient Diagram Method (CDM-PI) for a nonlinear pH neutralization system was proposed by Meenakshipriya *et al.* (2012), in which the set point tracking is compared with Ziegler Nichlos which described that CDM-PI gives better performance when compared with ZN-PI.

Direct synthesis technique of PI controller design (DSPI): The controller was designed based on the closed loop transfer function and the process model. In this approach, a significant relationship is existing between the process model and the controller (Foley *et al.*, 2005). Gain of the controller is closely associated with system gain K. Both are having inverse proportion so that the stability of the system is achieved. In this technique, controller gain multiplied by model gain remains constant. The PI controller settings are as follows (Seborg *et al.*, 2004):

$$K_c = \frac{1}{K} \frac{\tau}{(\theta + \tau_c)} \quad (3)$$

$$\tau_I = \tau \quad (4)$$

The key decision in this approach is the choice of tuning parameter. Rivera *et al.* (1986) has proposed choice for this design parameter.

IMCPI controller design: IMC based controller is best suited for first order process with time delay. But the IMCPI controller may produce better performance if the dead time is approximated in the controller design. The controller settings are as follows (Bequette, 2003):

$$K_c = \frac{\tau + \frac{\theta}{2}}{K\lambda} \quad (5)$$

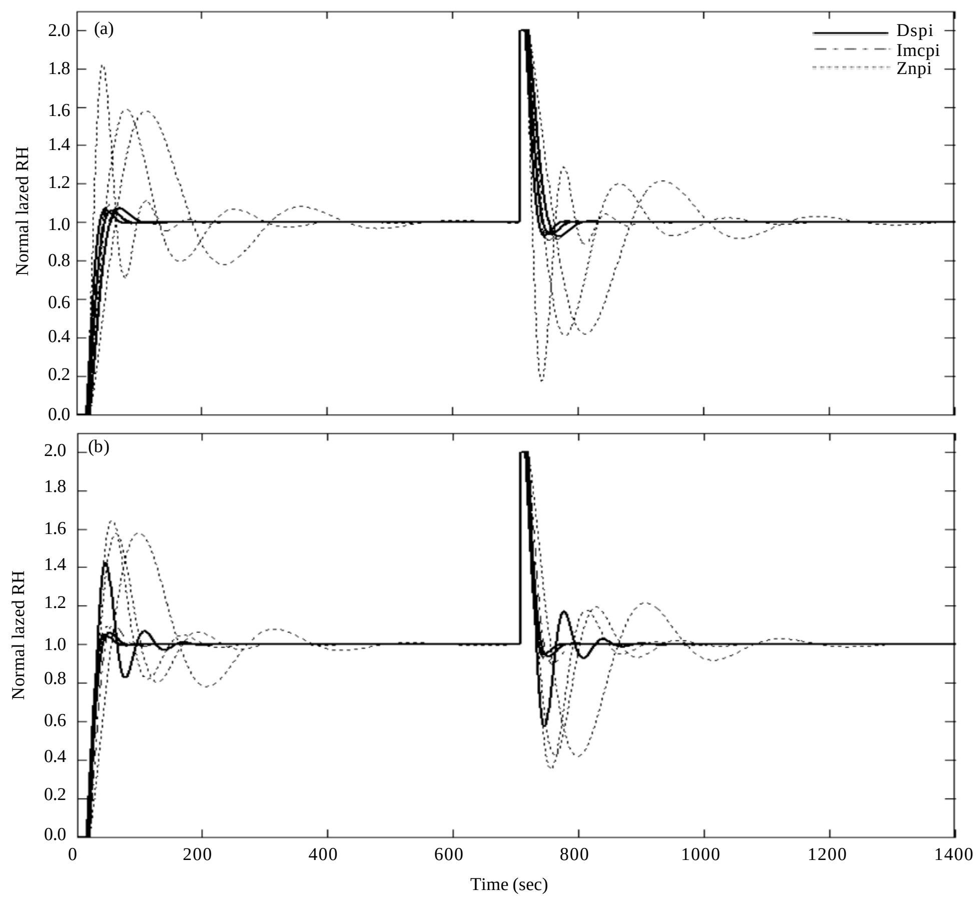

Fig. 3(a-b): Response of the controllers for set point and load changes for different operating regions (a) 1, 3 and 5 and (b) 2, 4 and 6

Table 2: Tuning parameters K_c and τ_I obtained for different controllers

Operating region	ZNPI		IMCPI		DSPI	
Tuning parameters	K_c	τ_I	K_c	τ_I	K_c	τ_I
1	0.0850	0.0880	0.00012	0.00012	0.0441	0.00120
2	0.1693	0.1064	0.00016	0.00025	0.0520	0.00160
3	0.1562	0.1678	0.00026	0.00024	0.0993	0.00340
4	0.2019	0.2177	0.00045	0.00042	0.1899	0.00714
5	0.2220	0.2274	0.00048	0.00047	0.2940	0.01230
6	0.3263	0.3398	0.00087	0.00085	0.2093	0.00960

K_c: Proportional term, τ_I: Integral term, ZNPI: Ziegler nichols proportional integral controller, IMCPI: Internal model control proportional integral controller, DSPI: Direct synthesis proportional integral controller

$$\tau_I = \tau + \frac{\theta}{2} \qquad (6)$$

The filter coefficient is playing significant role in designing the IMCPI controller.

RESULTS AND DISCUSSION

The model was identified for laboratory scale humidity. For the identified model, tuning technique such as ZNPI, DSPI and IMCPI were simulated using MATLAB. The tuning parameters are shown in Table 2. Unit step input was given to the process. The process was tested for both servo and regulatory problems. The initial condition of the process was taken as zero and unit step input was given to analyze the set point change. After the steady state was reached, a disturbance input was given to the process. Figure 3 show both set point and load changes of the process for all the six

Table 3: Time domain specifications for different controllers

Operating region	Different controllers	Rise time (t_r) (sec)	Peak overshoot (M_p) (sec)	Peak time (t_p) (sec)	Settling time (t_s) (sec)
1	ZNPI	42.0	0.581	111	518
	DSPI	55.0	0.074	68	94
	IMCPI	102.0	0.000	102	65
2	ZNPI	54.0	0.581	97	456
	DSPI	33.2	0.427	46	147
	IMCPI	45.0	0.103	58	81
3	ZNPI	45.0	0.590	79	355
	DSPI	42.0	0.092	53	73
	IMCPI	40.0	0.090	54	72
4	ZNPI	34.0	0.645	56	192
	DSPI	39.0	0.094	49	67
	IMCPI	37.0	0.091	48	65
5	ZNPI	27.0	0.825	42	157
	DSPI	37.0	0.075	46	62
	IMCPI	37.0	0.075	46	62
6	ZNPI	36.0	0.577	62	256
	DSPI	35.0	0.065	44	58
	IMCPI	35.0	0.064	43	58

regions. Table 3 shows the time domain specifications for all the three different controllers.

CONCLUSION

Since, humidity plays an important role in maintaining the quality of the product in industry as well as human comfort, an attempt has been made to maintain and control the same in the lab scale environment. The process model was obtained for the pilot humidity plant which was approximated with FOPDT model. The model also validated with calculated data. For the model obtained different PI control schemes were designed and simulated using MATLAB environment. The time domain specifications such as rise time, peak time, peak overshoot and settling time were found for both servo and regulator problems. From Table 3 it is evident that DSPI and IMCPI controllers are equally outperforming ZNPI in terms of faster settling time and lesser overshoot.

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