MICROCONTROLLER BASED MULTIVARIABLE CONTROL SYSTEM

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ABSTRACT

Industrial control systems are very complex and involve many interacting systems. To explain the behavior of such systems to the students and understand the controller designing aspects we need a benchmark system which can be used in laboratory. Multivariable Control for lab-in-a-Box system is an extension to the Single Board Heater System developed for demonstrating control system concepts. With the help of this system, we will be able to demonstrate various multivariable control concepts like system identification, multiloop and multivariable PID controller. In this paper we have given model of a 4×4 heater system and simulate a multiloop PI controller to control the temperatures.

Keywords:Multiloop Control, Multivariable Control, PI control

I. INTRODUCTION

One of the greatest challenges of engineering education is bridging the gap between theory and practice. From this point of view, hands on experimentation are extremely important [1]. Processes with only one output being controlled by a single manipulated variable are classified as single-input single-output (SISO) systems. Many processes, however, do not conform to such a simple control configuration. In the process industries for example, any unit operation capable of manufacturing or refining a product cannot do so with only a single control loop. In fact, each unit operation typically requires control over at least two variables, e.g. product rate and product quality. Many control systems in industry would have more than one input signals to drive more than one output signals and coupling effects are not negligible between those channels. All those imply that more approaches for control systems analysis and design are needed. In multivariable processes many strongly interacting variables are involved. Such multivariable systems can have such a complex interaction pattern that the adjustment of a single set point causes a profound influence on many other control loops in the process [2]. Multiloop control techniques solve issues of complex specification and modeling errors elegantly but the complexity of the underlying mathematics is much higher than presented in traditional single-input, single-output control system. Multiloop Control Systems focuses on control design with continual references to the practical aspects of implementation. One of the conventional approaches to multivariable control is to design Multiple Single Input Single Output PID controllers. However due to lack of coordination between different PID loops, Neighboring PID loops can co-operate with each other or end up opposing / disturbing each other. Relative Gain Array (RGA) and Singular Value Decomposition, SVD analysis provides a systematic approach to choose pairing of input-output variables for multi-loop control [3]-[4].In this paper we have developed a four input, four output system, where temperatures can be controlled by adjusting current inputs to the heater coils, mounted on a plate. RGA analysis is done to pair the controllers with the sensors and multiloop PI control is implemented. The paper is arranged as follows:

This paper is organized as follows: In the next section we describe the schematic diagram of the designed multivariable system. In section III, we describe details of multiloop PI controller and its tuning and Relative Gain Array (RGA) analysis for input output paring for controller design, In section IV, we present mathematical model obtained from the step tests and performance of multiloop PI controller.

II. HARDWARE DESCRIPTION

The multivariable control system comprises of a plate of size 7.5cm x7.5cm, made up of Tin. The objective is to control the temperatures in different regions of this plate. These heater coils are made up of Nichrome wire of 0.7mm diameter wound with 20 equally spaced helical turns into a coil. A computer fan is used to cool the plate from below for equal temperature distribution. A temperature transducer is stuck beneath the tin plate to measure the temperature. Plate is heated using 4 heater coils that are mounted as shown in Fig1.

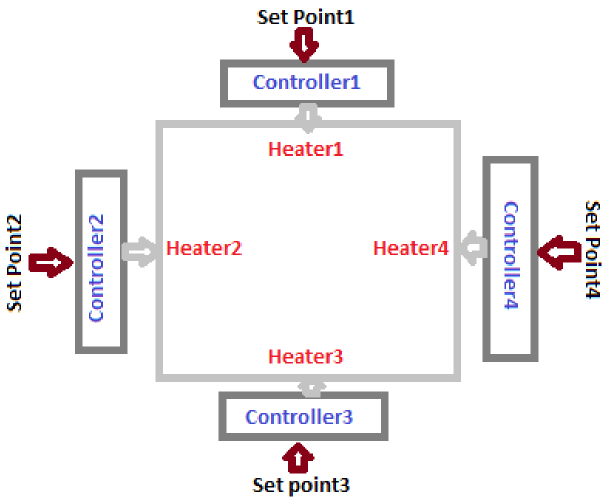

Fig.1: Schematic of the Process

III. MULTILOOP PI CONTROLLER

A MIMO control scheme is important in systems that have multiple dependencies and multiple interactions between different variables. Each manipulated variable depends on only a single controlled variable. This is called as multiloop control [6]. In this experiment the temperature of four heater coils controlled by four PI controllers. The equation for single PI controller in discrete form is given below

$$u(k) = K\left(e(k) + \frac{T_S}{T_I} \sum_{n=0}^{k} e(n) \right) \quad \text{--- (1)}$$

K -Proportional controller gain

T_I - Integral time constant

T_S -Sampling time

$u(k)$ -manipulated input

$e(k)$ - Error signal $e(k)$ is the difference between the reference signal (the set point) and the plant output (the measured variable).

3.1 PI Controller and Its Tuning

Proportional-integral (PI) controllers are widely used in industrial control systems because of the reduced number of parameters to be tuned. [7]. A proportional integral controller (PI controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PI controller takes an error value as the difference between a measured process variable and a desired set point an input. The controller attempts to minimize this error by adjusting the process through use of a manipulated variable. To tune PI controller, AMIGO (Approximate M-constrained integral gain Optimization), algorithm is used [8].In his method, we apply a set of equations to calculate the parameter of the controller in a similar way to the procedure used in Ziegler- Nichols method. The suggested AMIGO Tuning Rule for PI Controller is

$$K = \frac{1}{K_p} + (0.35 - \frac{LT}{(L+T)^2})\frac{T}{K_p L} \quad \text{--- (2)}$$

$$T_I = 0.35L + (\frac{13LT^2}{T^2 + 12LT + 7L^2}) \quad \text{---- (3)}$$

K- Proportional controller gain,

T_I -Integral time constant

K_p -Gain of the process

T-Time constant of the process

L-Process delay

One of the most important factors, common to all process control applications is the correct pairing of the manipulated and controlled variables. A number of quantitative techniques are available to assist in the selection process. One of the earliest methods proposed was RGA.RGAis an analytical tool used to determine the optimal input-output variable pairings for a multi-input-multi-output (MIMO) system. In other words, the RGA is a normalized form of the gain matrix that describes the impact of each control variable on the output, relative to each control variable's impact on other variables [9].

IV. IMPLEMENTATION RESULTS

4.1 System Modeling

In order to develop a controller for multiloop control system we must have a model of the system that describes the behavior of the system in response to changes in any of the inputs. To know the mathematical model of any system, we perform step test for the system and use system identification toolbox in MATLAB 2013 to obtain the transfer function models. We use the data of step test to obtain transfer function model using system identification toolbox in MATLAB. The transfer function matrix obtained is as follows:

$$G = \begin{bmatrix} \frac{0.06489e^{-6.825}}{33.839s+1} & \frac{0.03052e^{-30}}{31.022s+1} & \frac{0.032064e^{-21.001}}{46.257s+1} & \frac{0.071766e^{-5}}{46.024s+1} \\ \frac{0.090032e^{-5.533}}{47.527s+1} & \frac{0.11944e^{-5.01}}{55.58s+1} & \frac{0.051343e^{-1.001}}{56.051s+1} & \frac{0.049982e^{-14.011}}{50.47s+1} \\ \frac{0.047669e^{-1}}{67.305s+1} & \frac{0.066044e^{-14.958}}{34.42s+1} & \frac{0.1178e^{-2.157}}{31.563s+1} & \frac{0.055626e^{-1}}{52,525s+1} \\ \frac{0.038259e^{-1}}{46.834s+1} & \frac{0.033102e^{-30}}{36.929s+1} & \frac{0.025e^{-16}}{30s+1} & \frac{0.090711e^{-9.023}}{36.228s+1} \end{bmatrix}$$

A steady-state gain matrix can be used to determine the RGA.

$$G = \begin{bmatrix} 0.0649 & 0.0305 & 0.0321 & 0.0718 \\ 0.0900 & 0.1194 & 0.0513 & 0.0500 \\ 0.0477 & 0.0660 & 0.1178 & 0.0556 \\ 0.0383 & 0.0331 & 0.0250 & 0.0907 \end{bmatrix}$$

$$G^{-1} = \begin{bmatrix} 30.7358 & 0.4176 & -3.8381 & -22.1932 \\ -21.8702 & 11.5471 & -1.6114 & 11.9283 \\ 2.5023 & -5.2536 & 11.3851 & -6.0666 \\ -5.6722 & -2.9420 & -0.9309 & 17.7035 \end{bmatrix}$$

$$[G^{-1}]^T = \begin{bmatrix} 30.7358 & -21.8702 & 2.5023 & -5.6722 \\ 0.4176 & 11.5471 & -5.2536 & -2.9420 \\ -3.8381 & -1.6114 & 11.3851 & -0.9309 \\ -22.1932 & 11.9283 & -6.0666 & 17.7035 \end{bmatrix}$$

The Relative gain matrix is obtained as follows

$$\lambda = G.*[G^{-1}]^T \quad \text{---- (4)}$$

(.*) represents Schur multiplication. In this multiplication, first element of matrix G will multiply with first element of $[G^{-1}]^T$, second element of matrix G will multiply with second element of $[G^{-1}]^T$ and so on.

$$\lambda = \begin{bmatrix} 1.99 & -0.66 & 0.0803 & -0.4072 \\ 0.0375 & 1.37 & -0.2695 & -0.1471 \\ -0.1830 & -0.1063 & 1.3411 & -0.0517 \\ -0.8499 & 0.3948 & -0.1516 & 1.6057 \end{bmatrix}$$

Controller design pairing is done between input and output, where the relative gain array is closer to one. Hence we can select input-output pair as follows:

Table 1 Input-Output Pairing

Heater Input	Sensor Output
Heater1	Temperature Sensor1
Heater2	Temperature Sensor2
Heater3	Temperature Sensor3
Heater4	Temperature Sensor4

The controller gains used in the simulations and experiments are as follows:

$$K = \begin{bmatrix} 4.383 & 0 & 0 & 0 \\ 0 & 4.000 & 0 & 0 \\ 0 & 0 & 4.312 & 0 \\ 0 & 0 & 0 & 3.079 \end{bmatrix}$$

$$T_I = \begin{bmatrix} 0.739 & 0 & 0 & 0 \\ 0 & 0.540 & 0 & 0 \\ 0 & 0 & 0.265 & 0 \\ 0 & 0 & 0 & 0.496 \end{bmatrix}$$

Table 2 Proportional gain and Integral gain

Loop No	K	T_I
1	4.383	0.739
2	4.000	0.540
3	4.312	0.265
4	3.079	0.496

Simulations are carried out for 4000 samples. Set point changes are given as shown in table (3). Results of Simulation are given in Fig 2 and Fig3

Table 3 Set Point Change

Time instant	**Set point in degrees C**			
	S1	**S2**	**S3**	**S4**
1-859	36	37	34	36
860-1633	38	40	37	37
1634-3011	40	44	39	39
3012-4000	42	47	41	41

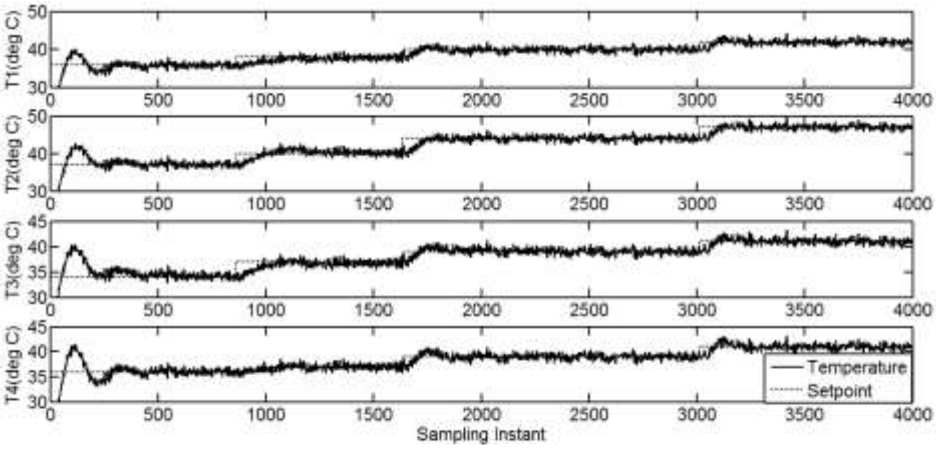

Fig.2: Measured Outputs

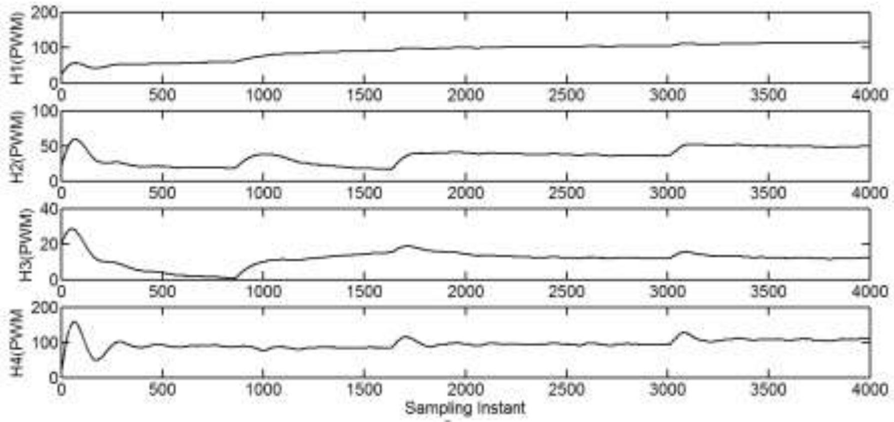

Fig.3: Manipulated Inputs

From the fig.2, we can say that all the set points are tracked by the multiloop PI controller and we can observe that when set point changes heater current also change to control the heater input.

V. CONCLUSION

A multivariable system has been designed to carry out multivariable control experiments to teach the concepts of multivariable control. In this paper we have presented simulation and experimental results on a 4x4 heater system. Multiloop PI controller has been developed based on RGA analysis. AMIGO tuning algorithm is used to tune the controller gains. Simulation and experimental results shows that the set points are tracked with an accuracy of 99%.

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