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Design and Control of an Air Heater Process

Abstract

The paper is concerned with the design of an air heater and experimental evaluation of feedback and feed forward control structures to achieve a desired heater outlet temperature by adjusting the heat load in the presence of a measured air flow disturbance. It was found that a combined feedback/feed forward control structure outperforms the simpler feedback only control structure. This experimental study entails the design of the air heater and associated instrumentation, real time data acquisition and control in LABView, process modeling, controller design, and evaluation of the performance of different control structures in a closed loop manner. This work was performed in partial fulfillment of the requirements of the Senior Capstone Project undergraduate course in controls and instrumentation at an Engineering Technology Department.

Introduction

Process control is part of our daily life. Our house A/C unit uses simple control techniques to maintain room temperature at a comfortable level. Manufacturing companies use process control and automation to gain competitive advantage. They use process control to run safely, environmentally friendly, reliably, and profitably their manufacturing operations. To be able to design and implement effective process control systems, we need to first understand what are and how the major components of a control system function. Process control includes a process, measuring devices (sensors), control algorithms (controller), and final control elements (controlled device). All these are combined in what is known as control loop. Different control algorithms and structures such as Feedback and Feed forward can be incorporated in a control system. Likewise, different tuning methods can be employed. Ziegler Nichols and Cohen-Coon methods. Different tuning methods result in different control performances.

Project Objectives

The specific project objectives are:

1. Construct the air heater unit (process)
2. Incorporate measuring devices (temperature sensors) and final control elements (heater power)
3. Develop a real-time data acquisition system using LABVIEW
4. Provide temperature control by implementing feedback and feed-forward control structures.
5. Develop empirical process models
6. Explore and apply different control principles (PID control algorithm, Ziegler-Nichols, Cohen-Coon and Auto tuning methods)
7. Test and analyze the performance of the different control structures and tuning methods
Description of the Air Heater Process

The Air Heater process is shown in Fig. 1. A fan, with adjustable speed, provides air which flows through the tube. A heating element is used to adjust the amount of heat and thus affect the air heater outlet temperature. Two-type K thermocouples are used to measure air temperature at two locations. LabVIEW was used to create a program for the controller graphic user interface (GUI) and is shown in Fig. 2. Also, LABVIEW was used to control the process. The LABVIEW program is shown in Fig. 3. The control structure is feedback only or a combined feedback/feed-forward structure, as shown in Fig. 4.

Fig. 1: Completed Project Air Heater Unit

Fig. 2: Graphic User Interface (GUI)
Fig. 3 LabView Program

Fig. 4: Feedback/Feedforward Block Diagram
Empirical Model Identification—Process Reaction Curve

In order to tune feedback controllers, a process model is required. An empirical process model in the form of first order plus dead-time was developed by using the Process Reaction Curve method. With this simple, open loop method, changes to the manipulated variables are made and the response of the controlled variable is observed. In our case, we introduced a series of step changes to the heat input (in controller output in %) and recorded the air heater outlet temperature (in deg F) as shown in Fig. 5.

By analyzing the data in Fig. 5, the following transfer function model was developed.

\[ G_p(s) = \frac{0.71 \cdot e^{-0.58s}}{4 \cdot s + 1} \]

It is a typical first order plus dead-time process model.
Proportional-Integral (PI) Controller Tuning

Once the process model was developed, tuning parameters were calculated using a number of methods and the system performance was evaluated as shown in Fig. 6. This figure shows the response of the control system when a temperature setpoint change of 10°F was applied (from 90°F to 100°F). Although all tuning methods provide good closed loop performance, the auto-tuning method outperforms the other two tuning methods, Ziegler-Nichols and Cohen-Coon.

![Comparison of Tuning Methods](image)

**Fig. 6: Closed Loop Feedback Only Control Using Different Tuning Methods**

All tuning methods achieve the desired setpoint in approximately the same settling time but the closed loop system response under auto-tuning does not exhibit overshoot. Also, the auto-tuning method results in the least overall absolute integral error.

Feedback & Feed forward Control Structure Results

To enhance the control performance in the presence of air flow disturbances, we designed and implemented a feedback and feed forward control strategy (see Fig. 4). The disturbance model was developed in a manner similar to the one used for the manipulated variable model. A series
of step tests in the disturbance (fan speed) were introduced at constant heat input. The temperature response data was analyzed and fitted to a first order plus dead-time model. The results of Fig. 7 show that the combined feedback / feed forward strategy outperforms the feedback only control strategy. For the same disturbance (change in speed fan), the combined feedback/feed forward control structure is able to maintain the temperature closer to setpoint than the feedback only control structure.

**Fig. 7: Comparing Feedback and Feedback/Feedforward Control Structure Performance**

**Summary**

This project was concerned with the design of an air heater and experimental evaluation of feedback and feed forward control structures to achieve a desired outlet temperature by adjusting the heat load in the presence of a measured air flow disturbance. It was found that a combined feedback/feed forward control structure outperforms the simpler, feedback only control structure.

Completion of this project required proficiency in a number of technologies including: electrical systems, instrumentation, real time data acquisition, process modeling, control structure development, and controller tuning.

A simple lesson was learned when dealing with control systems: someone must persevere through research, testing, and analyzing because there are more than just one way to solve a problem.
References