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MODELING AND CONTROL FOR THE HOT-AIR TEMPERATURE IN STENTER FRAME RANGE

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Abstract. *Modeling and control for the hot-air temperature in stenter frame range are presented in this paper. First, the model is set up by using mechanism modeling method and corrected through experiment. The relationship between input and output is showed clearly. Then, flows of air and oil are chosen as constants, which makes the process easier. A PID control algorithm is adopted. Finally, simulation and experiment results show that the proposed method performs well in accuracy and speed of response.*
Keywords: Modeling, Optimal control, Stenter frame range

1. **Introduction.** Heat setting is one of the most important processes in dyeing and finishing industry when warmed, synthetic fiber and its blend fabric are easy to produce shrinkage deformation. In order to keep the right size, gray fabric needs to be heated under suitable temperature and time [1].

Stenter frame range is the common instrument to fulfill the heat setting [2]. It is a large device with complex architecture which contains infeed section, chamber, cooling zone, outlet combinations, etc. Among them, the most important part is chamber. Usually, a stenter frame range has 8 to 10 chambers. The chamber is approximately of 3 meters length, and it includes nozzle system, heat exchanger, air circulation motor and so on, which is shown in Figure 1.

The heat exchanger discussed in this paper uses hot synthetic oil as its heat source. When cool air passes through the large heat exchanger, it will be heated. At the same time, hot air injects onto the surface of gray fabric vertically from the pores on the nozzle device with the help of air circulation motor. Then, the temperature of hot air drops, and the air will be reused in the new cycle.

Thus, the temperature of hot air is influenced by many factors, such as the structure of the heat exchanger, the flow of air and oil, the temperature of input air and oil. Fu et al. presented a numerical simulation of shell and tube heat exchanger fluid flow and coupled heat transfer, and it can provide a reference for the structure optimization design but is still difficult to be used in real-time control system [3]. Zhang et al. introduced a mathematical module used in heat-setting machine; dynamic relationship among hot air temperature, flux and temperature of heat transfer oil, flux of air is summarized; it is a pity that the module is still too complicated for engineers to design the controller [4]. Zhang and Yang introduced the fuzzy RBF neural network to do the modeling, and the needs of powerful computer in neural network training have limited the scope of this

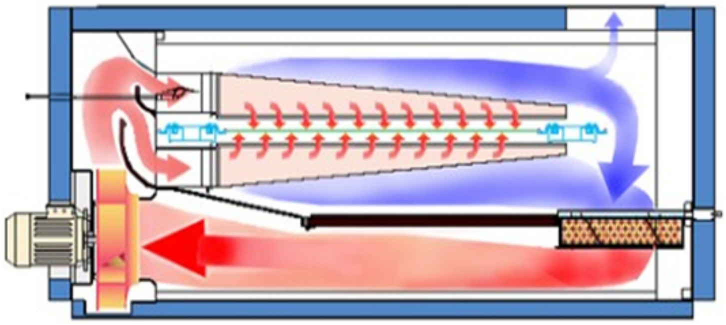

FIGURE 1. Chamber in stenter frame range

FIGURE 2. Hell-and-tube exchanger used in stenter frame range

algorithm [5]. Meanwhile, some researchers choose intelligent control algorithms which do not need mathematical model to control the temperature of stenter frame range, but it is not easy for general engineers [6].

In order to establish the relationship among the above parameters, the heat transfer process of heat exchanger is analyzed to build a mathematical model. Through analyzing, flows of air and oil are chosen as constants, and the temperature of oil is chosen as controlled variable. Compared with other models, this model is very simple and easy to control. Finally, a common PID control method is adopted and it works well both in simulation and real system.

2. **Problem Statement and Modeling.**

The core part of chamber is heat exchanger, which is shown in Figure 2.

Hot thermal oil is running inside the tubes and ambient air is blown through an outside fan. Based on the principle of energy balance [7], we have:

$$Q = \rho_{oil} u_{oil} C_{oil} \left(T_1 - T_2\right) \tag{1}$$

$$Q = \rho_{air} u_{air} C_{air} \left(t_2 - t_1\right) \tag{2}$$

where ρ is density, u is flow, C is specific heat capacity, T_1 is the temperature of input oil, T_2 is the temperature of output oil, t_1 is the temperature of input air, and t_2 is the temperature of output air.

This heat exchanger is forms of cross-flow, Q can be also written as:

$$Q = KA\Delta t_m = KA\left(\frac{T_1 - t_2 - T_2 + t_1}{\ln\left(\frac{T_1 - t_2}{T_2 - t_1}\right)}\right) \tag{3}$$

where K is the overall heat transfer coefficient, and A is the exchange area. When $(T_1 - t_2)/(T_2 - t_1) \leq 2$, the logarithmic mean temperature difference is very close to arithmetic average value. So,

$$\Delta t_m \approx \left(\frac{T_1 - t_2 + T_2 - t_1}{2}\right) \tag{4}$$

From Equations (1)-(4), it easy to derive that

$$\frac{2T_1 + (z-1)t_1}{(z+1)} = t_2 \tag{5}$$

where $z = (\rho_{air} u_{air} C_{air}) \left(\frac{2}{AK} + \frac{1}{\rho_{oil} u_{oil} C_{oil}}\right)$.

The overall heat transfer coefficient K can be described as:

$$\frac{1}{K} = \frac{1}{a_1} \cdot \frac{d_2}{d_1} + \frac{b}{\lambda} \cdot \frac{d_2}{d_m} + \frac{1}{a_2} = \frac{1}{a_1} \cdot k_2 + k_3 + \frac{1}{a_2} \tag{6}$$

where a_1, a_2 can be described as:

$$a_1 = 0.023\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3}\left(\frac{\mu}{\mu s}\right)^{0.14} = k_4 u_{oil}^{0.8} \tag{7}$$

$$a_2 = c\varepsilon \mathrm{Re}^{0.65}\,\mathrm{Pr}^{0.4} = k_5 u_{air}^{0.65} \tag{8}$$

where k_2, k_3, k_4, k_5 are constants.

In practical control system, it is very difficult to get good result if all of input parameters need to be considered as variables. In Equation (5), the most powerful method is set z as constant. In this case, the heat transfer coefficient K, u_{air}, u_{oil} need to be constants. In real system, $u_{air} = 5.556\mathrm{m}^3/\mathrm{s}$, $u_{oil} = 18\mathrm{m}^3/\mathrm{s}$, $K = 46.92\mathrm{W}/(\mathrm{M}^2{}^\circ\mathrm{C})$.

Here t_1 is the temperature of input air, that is, the temperature of reused air. It changes little during the production process which can be considered as agitation error. Equation (5) shows that output t_2 is a linear function of T_1.

Here, the input hot synthetic oil was produced by heating furnace which has be widely studied. The transfer function is shown in the following:

$$G(s) = \frac{k'}{TS + 1} e^{-\tau s} \tag{9}$$

By using curve fitting method in experiment, we get:

$$k' = 18.6, \quad T = 35.3, \quad \tau = 2.1.$$

Then, the problem of this temperature control process can be seen as common control problem in first order and time-delay system with agitation error.

3. **Experimental Results.** The stenter frame range discussed in this paper is called Glotech Platinum. In order to have a better control effect, the electrical control system is redesigned, DCS (WebField JX-300XP DCS, Produced by Supcon) is chosen as the core of new system, IO cards are selected to deal with input and output signals, and other sensors were also adopted.

The simulation results are shown in Figure 3.

Using the proposed model and PID control algorithm, the actual value can reach set value quickly and smoothly.

Also the experiment is done on the real stenter frame range, and the experimental results are shown in Figure 4.

From Figure 4, it shows that when set value equals 128°C, the actual value can achieve the goal in a relatively short period of time about 10 minute without large overshoot, and remain stable later. Meanwhile, there are still some small fluctuations. The difference still remained between real system and math model needs further studies.

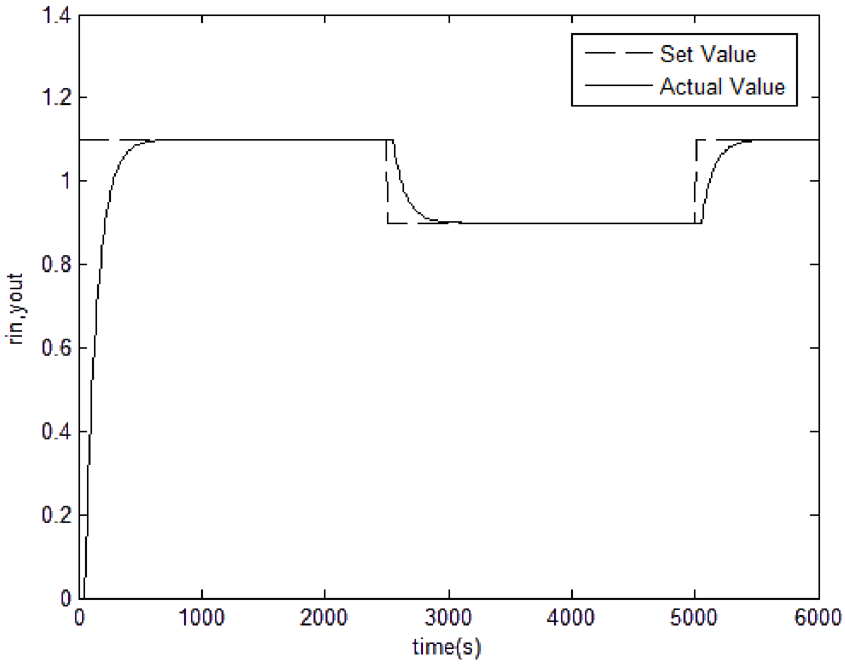

FIGURE 3. The simulating results of PID control algorithm

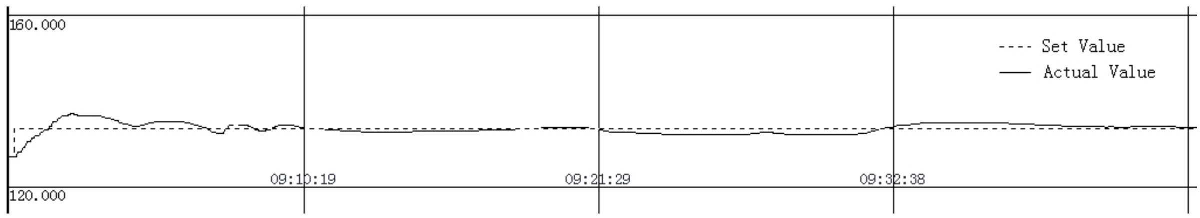

FIGURE 4. Control result of output air temperate

4. **Conclusions.** This paper has studied the problem of hot air temperature control in stenter frame range. By employing combination of mechanism and experiment methods, a new math model has been built. An easier control strategy has been adopted and satisfactory results have been obtained. The further work may focus on the difference between real system and math model and use intelligent control algorithm.

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