Simulation analysis of a water heating control system

Kehan Yan*
Wuhan University of Technology, Wuhan, Hubei Province, China

*Corresponding author email: kehanyan@whut.edu.cn

Abstract. As the need of accurate indoor temperature continuously growing in northern part of the world, the drawbacks of current water heating control system are becoming prominent. In order to improve its efficiency, using simulation method to analyze water heating control system and putting forward optimized PID parameters are important. This paper clearly explains the reason of its drawbacks and proves feasibility the of a optimization design, which is pivotal to further studies.

Keywords: simulation, water heating control, model, PID.

1. Introduction.
Water heating using coal as its main fuel, usually adopt cogeneration, regional boiler rooms or scattered small boilers. Thus, it has good characteristics such as high thermal efficiency, but in practice masses of problems appeared including a huge heat loss, atmospheric pollution, poor security assurance and a lack of accurate control.

At present, accurate control of indoor temperature is strongly in demand. Although there are two control methods for accurate temperature control, namely room temperature switch and shunt bimetal temperature control. The temperature control switch and the shunt bimetallic strip cannot effectively control the temperature balance of a larger area, resulting in partial high temperature or partial low temperature, even at a huge installation cost.

Therefore, I joined the one of my upperclassman’s team to jointly study an indoor temperature accurate control technology based on the appliance of neural network and PID control with low reconstruction cost, and provide optimized parameters of a new type of water and heat control device for smart home.

2. Problem statement.
Though we have made some breakthrough in aspects of product structure, wireless communication, single chip microcomputer control, but whether this product can save more economic interests of the users in comparison of traditional ones has been bothering us deeply.

I hope to get the overshoot, peak time, transition process time and other related performance indexes of traditional shunt bimetal control warm water through this simulation and put forward the PID control optimization scheme to provide reliable theoretical data for the benefit analysis of the whole project.
3. Approach.

3.1. Create mathematical model

The control part of this project is based on STC89C52 single chip microcomputer, which is mainly composed of wireless communication module, displacement sensor module, motor module and temperature sensor module. As shown in figure 1, users can set different temperature for different room through interact with the APP. Flux sensor is used for monitoring the water in pipes, motor is applied for adjust water valve and temperature transmitter is used for continuously monitoring the temperature of the room and collecting environmental data. The general control flow is shown in figure 1.

Several assumptions of mathematical modelling: First, water in the water heating is an ideal liquid. During the whole working process, the pressure of the internal liquid is not too high, and the temperature of the internal liquid is far away from their critical parameters. Second, the volume of the room remains unchanged in the process of water heating, and the radiation heat transfer in the interaction between the room and the outside is neglected. Third, the thermodynamic change of the liquid system in the pipeline is a quasi-static process.

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**Figure 1** control flow

**Figure 2** Mathematical model
The proportional overflow valve is the core element of the pressure closed-loop control system, which mathematical model is complex. It is simplified as a second-order system model for the convenience of analysis and research [1].

\[ G(s) = \frac{1}{\omega_1^2 s^2 + 2\xi_1 \omega_1 s + 1} \]

Where: \( \omega_1 \) which means the inherent frequency of proportional overflow valve is 2.1 rad/s, \( \xi_1 \) which means the damping ratio of proportional overflow valve is 0.7.

The circuit diagram of the heating boiler is shown in figure 3, and its thermal system can be expressed as follows:

\[ Q = C_a \frac{d\theta_a}{dt} + C_m \frac{d\theta_m}{dt} + \frac{\theta_a - \theta_c}{R_f} \]

Where, \( \theta_m = \theta_n - C_m R_m \frac{d\theta_m}{dt} \)

The Laplace transform of this is going to be,

\[ \theta_a = (Q + \frac{\theta_c}{R_f}) + \frac{R_m(1 + R_m C_m)}{1 + (R_m C_m + R_f C_m + R_f C_a) s + R_f C_m R_f C_a s^2} \]

\[ T_i \frac{d\theta_c}{dt} + \theta_a = K_i (\theta_m + \theta_i) \]

As the control object of the water temperature control system has the characteristics of large heat storage capacity and large inertia. There is a certain resistance to the flow of water or heat transfer in the container, so the controlled variables can be attributed to an inertial link. The value of each parameter can be obtained by referring to the nameplate of the heating boiler.

![Boiler circuit diagram](image)

**Figure 3** Boiler circuit diagram

\[ G(s) = \frac{K_i e^{-ts}}{T_i s + 1} \]

Where: \( K_i \) is 4, \( T_i \) is 0.08.
As the displacement sensor is beyond my knowledge, I refer to some papers \cite{234} in dealing with similar problems. I simplified the modelling of temperature control transmitter and flow sensor and got the mathematical model of the system as shown in the figure\ref{fig:mathematical_model_simulink}.

![Mathematical model in Simulink](image)

**Figure 4** Mathematical model in Simulink

3.2. Stability analysis

3.2.1. Use Pole-Zero Map to judge

![Pole-Zero Map](image)

**Figure 5** Pole-Zero Map

\[
G_s = \frac{4}{0.01814s^3 + 0.2801s^2 + 0.9067s + 4.6}
\]

The closed loop poles of the system:
-13.1025 + 0.0000i
-1.1687 + 4.2411i
-1.1687 - 4.2411i

The System is stable.
3.2.2. Use Nyquist-Map to judge

![Nyquist Diagram](image)

**Figure 6** Nyquist Diagram

$$G_k = \frac{4}{0.01814s^3 + 0.2801s^2 + 0.9067s + 3}$$

The System is stable.
3.3. Time domain analysis

Peak time =0.8224
Max overshoot =39.6177
Rise time =0.3093
Settling time =3.2406
Steady state error =0.1304

As is clearly revealed in the statistic and diagrams above, it is certain that the rapidity and the stability of this system is good but this system is poor at accuracy.

3.4. Frequency domain analysis

Resonant Peak =4.8847
Resonant Freq = 2.9471
Band width = 5.6899

![Figure 8 Bode Diagram](image)

What is illustrated in the frequency domain analysis is correspond with the conclusion that is drawn in time domain analysis, which in return assure the correctness of the analyses.

3.5. **PID optimizing**

After several trial, I have found the best $K_p$, $K_i$, $K_d$ that match the system better.

They are: $K_p = 3$,

$K_i = 6$, 

$K_d$,
\( K_d = 2 \).

Taking the remote-control ability of the water heating control system which I want to create, this PID controller is able to sacrifice the rapidity of this system pursuing better accuracy. Because users can set system into working long before they need it by using the APP in their smart phone.

**Figure 9** Mathematical model in Simulink with PID control

Without disturbance:

With disturbance:
Figure 10 the scope of Simulink with PID control

4. Conclusion.
After days of industrial working on this project, I have made it clear that traditional water heating control system has it poor performance in accuracy. Graphs show that it is difficult of traditional water heating to accurately control the temperature of a single room or a specific small area, and explain why there is about 25% energy waste in its usage. The simulation parameters and result have great significance in practical use to control the heat.

However, there is also some deficiency in my simulation analysis. First, the delay cause by the water flow and the heating transition process have not been counted in my analysis. It may lead to the overestimate of the rapidity of this water heating system. Secondly, the statistics of parameters used in my simulation analysis are measured theoretically, when it comes to practice there will be some tiny differences.

To sum up, this simulation analysis reinforces my understanding of knowledge and enhance my reaching and study ability. The statics from the simulation analysis will be crucial for further study.

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