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Research and design of electric heating system for constant temperature control equipment

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Abstract. In constant temperature control processing, the heating system is the first and important step. High heating control efficiency and accuracy of constant temperature control equipment directly guarantee the efficiency of the entire production process. Through the installation, commissioning and trial operation, electric heating system for constant temperature control equipment is designed, which can stably and accurately control the temperature of the equipment to the target temperature through manual and automatic control, can quickly make adjustments during the disturbance process. After the application of technology promotion in many companies, this system successfully completes the reservation aims.

1. Introduction

Heating system is the first step in constant temperature control processing, and its efficient control can lead to higher production efficiency. There are many factors that limit the degree of automation of poultry slaughtering equipment. Among them, in the first few processes, the core of scalding and hair removal is efficient heating control. At present, the production process is too much manual control, the inaccurate parameter adjustment causes damage to raw materials and other factors that seriously affect the production efficiency of the entire production line. Increasing the heating efficiency of the scalding and wax pool can greatly improve the automation of the entire production line and improve productivity.

2. Control system design

After research and development on the surrounding poultry slaughtering equipment, production enterprises and equipment users, the general poultry slaughtering pool was selected to design and produce a poultry slaughtering experimental prototype, as shown in Fig. 1, which is made of 304 stainless steel, and the water inlet and outlet are realized by manual and solenoid valves.

2.1. Heater selection

Four sets of high-quality stainless-steel heating wire are used, which power is 3000W, rated voltage is 220V. mounting thread is 1.5-inch/DN40-diameter and heating part length is 230mm.

The outer casing of the equipment is provided with four internal threaded mountings with an inner diameter of 40mm. It is made of 304 stainless steel and is welded to the side of the equipment. It is 150mm from the bottom and spaced 300mm apart. The heating wire is sealed by a raw material tape and a silicone gasket, as shown in Fig. 2.



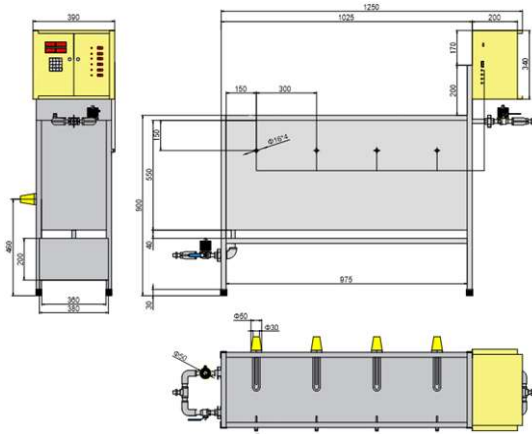


Figure 1. Main design drawings of poultry slaughter soup pool



Figure 2. Custom heater physical map and overall installation diagram

The main circuit part is powered by a single-strand copper wire of 4 m² wire diameter. The heater is powered by AC 220V and BV2.5 copper wire.

1 set of heater power 3000W, rated current is

$$I_1 = P/U = 3000W/220V = 13.64A \quad (1)$$

According to the rated current carrying capacity of the single-strand copper wire, the rated current of the BV2.5 copper wire is

$$I_2 = 2.5mm^2 \times 9A/mm^2 = 22.5A \quad (2)$$

4 sets of heaters and other power parts of the equipment are evenly arranged to each phase of the three-phase power supply. The neutral conductor is made of BV 10mm² multi-core cable, which consists of 7 single-strand copper wires with a diameter of 1.35mm, according to the multi-strand copper core cable. Rated current capacity calculation, its rated current is

$$I_3 = 10mm^2 \times 6A/mm^2 = 60A \quad (3)$$

The maximum total current of the four sets of heaters is 54.56A, and the power of other parts is too small to be negligible. In summary, the power supply system of the heating section meets the conventional technical requirements.

2.2. System heating efficiency calculation

2.2.1. *Ideal state heating efficiency.* The maximum water storage capacity of the designed hot pool is

$$600mm \times 300mm \times 1200mm = 0.216m^3 \quad (4)$$

The mass is about 216kg, the initial value of water temperature T1 is set to 20°C, the water temperature of poultry hot pool T2 is 61°C-62°C, the specific heat of water is C=4.18kJ/kg, the total heating power of 4 sets of 220V/3000W electric heating is 12000W. Under the ideal condition of absolute heat preservation and no heat dissipation, the heat required to heat the water temperature from room temperature to the target temperature is

$$Q = m * C * (T_2 - T_1) = 216 \text{ kg} * 4180 \text{ J/kg} \cdot ^\circ\text{C} * (62 ^\circ\text{C} - 20 ^\circ\text{C}) = 37920960 \text{ J} \quad (5)$$

Time required for the heating process is

$$t_0 = Q / P = 37920960 \text{ J} / 12000 \text{ W} = 3160.08 \text{ s} = 52.668 \text{ min} \quad (6)$$

2.2.2. Actual heating efficiency. The actual situation must consider the heat dissipation problem of the equipment. It is divided into two aspects, referring to the heat loss curve of the water surface, as shown in Fig. 3.

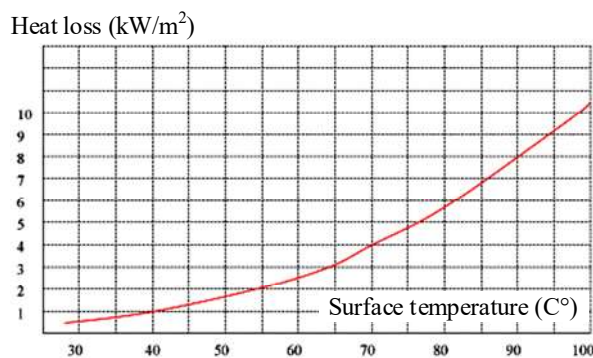


Figure 3. Heat loss curve of water surface (environmental temperature 20 °C)

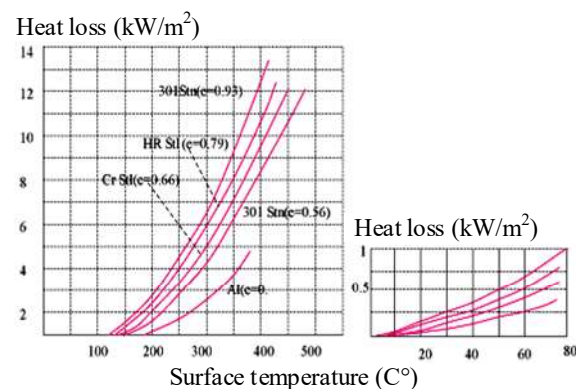


Figure 4. Heat loss curve of uninsulated 304 stainless steel surface (environmental temperature 20 °C)

During the process of changing the water surface temperature from 20 °C to 60 °C, the heat loss on the water surface is estimated from 0.5 kW/m²-2.5 kW/m². The heat loss on the water surface is 1.5 kW/m², and the hot water area is

$$300 \text{ mm} * 1200 \text{ mm} = 0.36 \text{ m}^2 \quad (7)$$

Therefore, the heat loss in the hot pool during heating from room temperature to the target temperature is about

$$\Delta P_1 = 1.5 \text{ kW/m}^2 * 0.36 \text{ m}^2 = 0.54 \text{ kW} = 540 \text{ W} \quad (8)$$

Refer to the heat loss curve of the uninsulated 304 stainless steel surface, as shown in Fig. 4.

During the process of changing the surface temperature of stainless steel from 20 °C to 60 °C, the heat loss is estimated from 0.2 kW/m² - 0.4 kW/m², and the stainless-steel area is

$$600 \text{ mm} * 300 \text{ mm} * 2 + 600 * 1200 \text{ mm} * 2 + 300 \text{ mm} * 1200 \text{ mm} = 2.16 \text{ m}^2 \quad (9)$$

Therefore, the heat loss from the stainless-steel surface of the hot pool during heating from environmental temperature to the target temperature is

$$\Delta P_2 = 0.3 \text{ kW/m}^2 * 2.16 \text{ m}^2 = 0.648 \text{ kW} = 648 \text{ W} \quad (10)$$

The overall heat loss of the equipment is

$$\Delta P = \Delta P_1 + \Delta P_2 = 540 \text{ W} + 648 \text{ W} = 1188 \text{ W} \quad (11)$$

Then the actual heating power becomes

$$12000 \text{ W} - 1188 \text{ W} = 10812 \text{ W} \quad (12)$$

The actual heating time will be extended to

$$t = Q/P = 37920960 \text{ J} / 10812 \text{ W} = 3507.3 \text{ s} = 58.5 \text{ min} \quad (13)$$

It can be seen that the heat lost through the surface of the device is large, which affects the heating efficiency of the device and prolongs the working cycle of the device. Therefore, the product heating efficiency will be effectively improved by equipping with an insulating material such as aluminum silicate or glass wool.

2.3. Heating system control

The control circuit is divided into two types: manual control using ship type switch and power electronic control mode using photocoupler, which is convenient for emergency situations and efficient control of equipment heating system.

2.3.1. Manual control. The manual control controls the operation of 4 heaters by the ship type switch, as shown in Fig. 5.

The switch has a red turn-on indicator, rated current 15A, rated voltage AC 250V. Each ship switch is manually controlled by a dual-core BVVR 2.5 sheathed cable to a dedicated terminal on the heating control board. The front panel of the prototype controller is shown in Fig. 6.



Figure 5. Physical diagram of custom manual heating control switch



Figure 6. Physical diagram of front panel of prototype controller

2.3.2. Automatic control. The automatic control of the heater is realized by the bidirectional thyristor (TRIAC) control method. The schematic diagram of the TRIAC control of the heating system is shown in Fig. 7.

The TRIAC is a five-layer, three-terminal (T1, T2, and G) component of the NPNPN structure with 4 PN junctions. It can be considered as the integration of a pair of common TRIAC in anti-parallel connection. It has two main electrodes T1 and T2 and one gate G. The gate causes the device to trigger conduction in both the positive and negative directions of the main electrode, so the TRIAC has symmetric volt-ampere characteristics in the first and third quadrants. This characteristic is the same as the forward characteristic of a normal TRIAC. Its electrical graphical symbols and volt-ampere characteristics are shown in Fig. 8.

Regardless of the polarity of the voltage between T1 and T2, if a positive trigger current (I_G flows into G, flows out from T2) or a negative trigger current (I_G flows into T2 and flows out from G) is applied between gate G and main electrode T2, then the TRIAC can be turned on. Depending on the polarity of the voltage applied between T1 and T2 and the polarity of the control gate signal, there are 4 modes of operation for the TRIAC as shown in the Table 1.

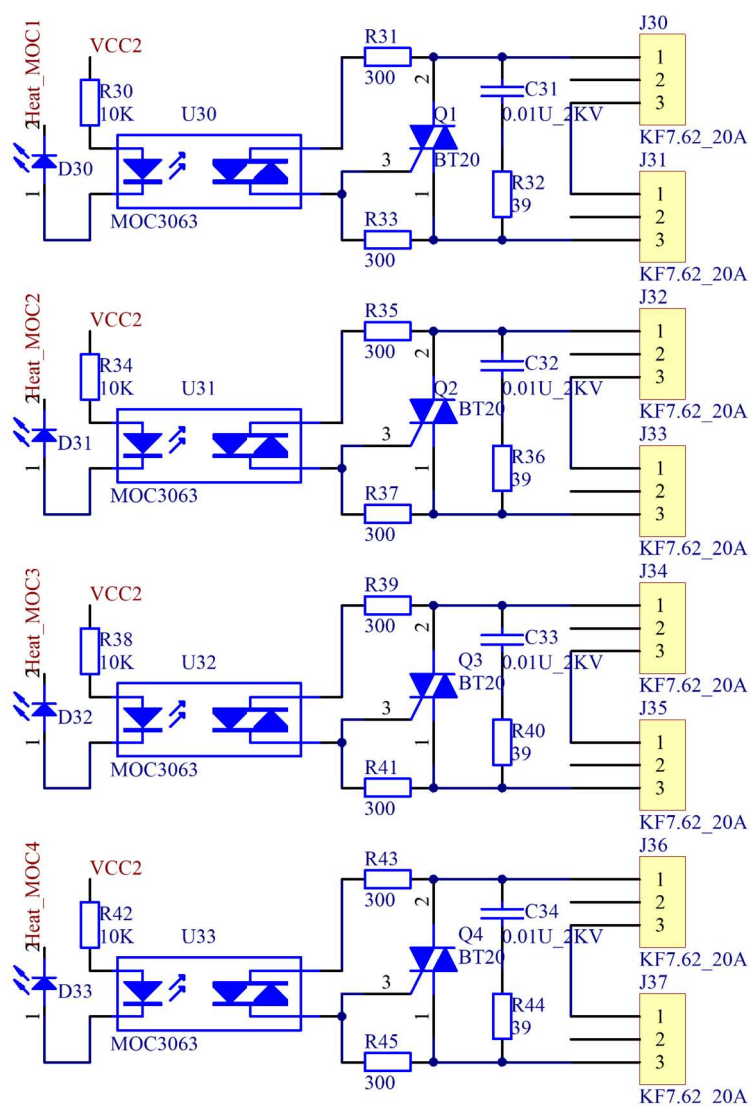


Figure 7. Schematic diagram of the prototype heating system

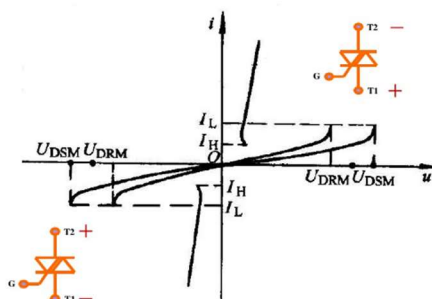


Figure 8. Electrical graphic symbols and volt-ampere characteristics of a TRIAC

Table 1. Working mode of TRIAC

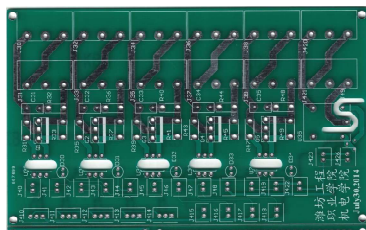
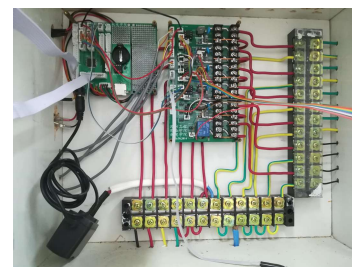
Trigger mode	Anode voltage polarity(U_{T1T2})	Gate trigger voltage(U_{GT2})	Trigger sensitivity	Usage
I +	>0	>0	Higher	Commonly used
I -	>0	<0	Lower	Commonly used
III+	<0	>0	Lowest	Generally not used
III-	<0	<0	Higher	Commonly used

The trigger sensitivity of the device is different in different working modes, and the sensitivity in the III+ mode is the lowest. Therefore, I-, III-mode or I+, III-modes with higher sensitivity are commonly used in practical applications.

The TRIAC is used in the AC circuit, and the rated current is defined by the effective value. The nominal 20A TRIAC can only pass the current with 20A effective value. The rated current of the single heater of the poultry slaughter prototype is 13.64A. The heater control circuit is a No inrush current load. For safety reasons, 40% of the current margin is reserved, and the safe current is 19.096A. Therefore, the equipment adopts the BTA20 model. The TRIAC, rated at 20A on-state current, is equipped with an aluminum alloy heat sink to meet the control requirements of the system.

The control circuit is connected in parallel with the RC resistor-capacitor absorption circuit composed of a high-power component 39 Ω resistor and a 0.01 μ F capacitor at both ends of the components T1 and T2 to limit the excessive du/dt caused by the step back voltage to ensure the normal operation of the circuit.

Using the zero-crossing trigger mode, the control signal from the microcontroller pin is transmitted through the photocoupler MOC3063. The signal provides the gate control signal to the TRIAC to determine the conduction law of the TRIAC. In this way, the heating is controlled indirectly to assist the automatic control of the system. In order to ensure the normal operation of the optocoupler and avoid the interference of strong electricity, the circuit board is windowed under the photocoupler chip, as shown in Fig. 9.

**Figure 9.** Design of the power control circuit system**Figure 10.** Internal control wiring map

2.4. Control system design

The front of the system control cabinet is designed with digital tube high-brightness display, matrix 16-key integrated keyboard system, ship type switches to manually control heating system, indicator lights and other functional modules, as shown in Fig. 9. The temperature acquisition system uses a high-efficiency digital temperature sensor DS18B20 to achieve multi-point temperature detection.

In order to maximize the interference between the strong and weak current, the main control board of the controller and the heating control module are separately installed inside the control cabinet. The main control board contains core functions such as display, perpetual calendar and report storage etc., implements control functions through the aviation connection line. As shown in Fig. 10.

The strong electric circuit controlled by the TRIAC needs to control the heater to complete the heating. In order to reasonably match the current of the circuit board and the current of the strong electric

wire, the heating control circuit is designed by the mode of double-sided widened wiring on the bottom layer and the top layer. open corresponding window on the solder mask layer. During the assembly and soldering process of the control board, all the circuits that need to pass the strong electric circuit are processed by tinning. Effective control of the system can be completed for a long time by these multiple methods.

3. Conclusion

Through the installation, commissioning and trial operation of the whole system, this heating system can stably and accurately control the water temperature of the equipment to the target temperature through manual and automatic control, can quickly make adjustments during the disturbance process, and successfully complete the reservation aims. After the promotion and application of several companies, the heating system completed the heating function of the equipment efficiently in a reasonable time.

Acknowledgments

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