Automatic Testing Design for Thermal Performance of Domestic Solar Water Heating Systems Based on PLC

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Abstract: This paper mainly introduces the method of using PLC to realize the automatic test for the thermal performance of the domestic solar water heating systems, including 4 functional modules as automatic water temperature control, automatic water supply control, automatic circulation control, and automatic data collection control. Through verification, it can meet the test requirements of the standard GB/T18708-2002 "Test Methods for Thermal Performance of Domestic Solar Water Heating Systems".

1. Introduction
Thermal performance of domestic solar water heating system is a measure of the most important performance parameters, including daily useful energy and average heat factor. As the first compulsory standard, GB 26969 "Minimum allowable values of energy efficiency and energy efficiency grades for domestic solar water heating system", requires that domestic solar water heating systems must meet the standard before they can be sold in the market. At present, most of the testing in the industry is done by manual operation, the level of automation is lower. So, we designed an automatic testing method based on PLC.

2. Automatic Testing Design Basis
This automatic testing design is based on GB/T18708-2002 "Test Methods for Thermal Performance of Domestic Solar Water Heating Systems", includes daily useful energy and average heat loss factor.

2.1. Daily useful energy

2.1.1. Conception and Calculation formula
The daily useful energy is mean that when the solar water heating system under a certain irradiation and the water temperature in the water storage tank is not less than a specified temperature, the energy obtained by water in the water storage tank per unit contour aperture area. The calculation formula as follow:

\[ q = \frac{17c_{pw}m(t_e - t_b)}{10^6A_cH} \]

H: actual irradiation; \(c_{pw}\):water specific heat; m: water quality of water storage tank; \(t_e\): water final temperature; \(t_b\): water initial temperature;\(A_c\): measurements of counter aperture area.

2.1.2. Testing methods:
Before the testing, cover the collector, open the mixing pump, mix the water in the water heating tank evenly at a flow rate of 400~600L/h. If the temperature at the entrance of the water storage tank does not change more than 0.2℃ within 5 minutes, it is regarded as water mixed well and record the data.
When the time reaches 4h before midday sun, the visor was opened and the test started. When the time reaches 4h after midday noon, cover the collector and collect the data.

There have two methods drainage and mixing to collect the data at the end of the test. The mixing method is the same as the operation method before the test, and record the finally temperature \( t_e \). The drainage method is to inject cold water at the inlet of the water storage tank to make the hot water flow out of the water tank at a flow rate of 400~600L/h, and record the water temperature every 15s until the difference between inlet and outlet is \( \pm 1^\circ C \).

2.2. Average heat loss factor

2.2.1. Conception and Calculation formula

The average heat loss factor is mean that when no irradiation, the difference between water temperature in water storage tank and ambient temperature is 1k, the average heat loss of the solar water heating system per unit time and volume. The calculation formula as follow:

\[
U_{SL} = \frac{\rho_w c_{pw}}{\Delta \tau} \ln \left( \frac{t_i - t_{as(\text{av})}}{t_f - t_{as(\text{av})}} \right)
\]

\( t_{as(\text{av})} \): ambient temperature; \( c_{pw} \): water specific heat; \( \Delta \tau \) is test period; \( \rho_w \) : water density; \( t_i \): water initial temperature; \( t_f \): water final temperature.

2.2.2. Testing methods

Before testing, heat the water in the water storage tank to above 50℃, open the mixing pump to make the temperature of the water in the water storage tank evenly mixed. If the temperature at the inlet of the water storage tank does not change more than 0.2℃ within 5 minutes, it is regarded as water mixing evenly and record the data, and start the testing.

The test period is 8 hours. When the test reaches 460 minutes, open the pump to bring temperature of the water in the pipeline to \( t_i \). At 465 minutes, switch the valve of the pipeline, turn on the circulating pump to make the water temperature in the water storage tank evenly mixed, and record the water temperature \( t_f \).

3. Realization of Automatic Control Function

The automatic control part adopts the combination of PLC and touch screen, including 4 functional modules as automatic water temperature control, automatic water supply control, automatic circulation control, and automatic data collection control. The composition of control system as Fig.1.
3.1. Automatic Water Temperature Control
The automatic control of water temperature is the control of the basic water temperature before the test. Here we have a preliminary water tank to provide water that meets the requirements. At the same time, this water tank is also used to collect the water discharged from the system after the test. Temperature sensors, electric heater, and condenser installed in the preliminary water tank. The basic water temperature of the daily useful energy is required to be 20±1℃, and the basic water temperature of the average heat loss factor is controlled above 50℃. Set the water temperature value as required in PLC, The water temperature in the water tank is transmitted to the PLC CPU in the form of an analog signal which collected by the water temperature sensor. After processing and judging by the CPU, transmits it to relays in the form of a digital signal to control the starting and stopping of the electric heater and the condenser, so as to reach the set water temperature.

3.2. Automatic Water Supply Control
Automatic water supply is to inject required water into the system from the preliminary water tank. Connect a water pump between the reserve water preliminary tank and the solar water heating system, and install a water level sensor in the water storage tank. Set the water supply time and water level in the PLC. When the water supply time is reached, the CPU outputs digital signal to trigger the relay, and the water pump turned on. When the water level signal received by the CPU is the same as the set value, it is determined that the water in the water storage tank is full, and then the relay is triggered to turn off the water pump.

3.3. Automatic Circulation Control
Automatic circulation is the procedure before and after the test. The temperature sensor is installed at the inlet of the water storage tank, the water pump and flow meter are installed in the pipeline, set the test circulation time and required water flow in the PLC. When the circulation time is reached, the CPU will send a digital signal to the relay to turn on the water pump. The flow meter transmits the received water flow signal to the analog module, and then passes it to the frequency converter of the water pump after being judged by the CPU to make the water flow meet the requirement. The water temperature signal collected by the water temperature sensor at the inlet is transmitted to the CPU through the analog module, the CPU judges the maximum and minimum values within 5 minutes and compares them until the difference less than 0.2℃, at this time, a digital signal is sent to the relay to turn off the water pump.

3.4. Automatic Data Collection Control
The temperature, irradiate, and water level signals which input from the analog module transferred to touch screen by the CPU of PLC through A/D conversion and data conversion. In addition, set the PID parameters on the touch screen, and send instructions to the PLC to control the pump, electric heater and condenser, so as to realize the real-time display of testing data and equipment statues. Use configuration software to save, query and process testing data in the background.

Taking the drainage method as an example, the curve drawn using the collected data as Fig.2.:
4. Conclusion
This test method has been applied in the enterprise, and the equipment has been measured and calibrated by the National Institute of Metrology, all meet the requirements. Since the automatic testing method reduces a lot of manual operations, improves work efficiency, and also improves the detection level, so it has great significance for the solar energy industry’s development.

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