Design and Research of High-accuracy and Intelligence Test Device for Gas Water Heater Energy Efficiency

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Abstract. The research subject aims to solve the defects of slow test speed and inefficient for gas water heater energy efficiency. It not only applies modern sensor technology, high reliability data acquisition card, solenoid valve control technology and stable industrial computer, but also adopts LabVIEW language, PID control technology and flow stability judgment algorithms to develop an efficient, accurate and intelligent test system for gas water heater energy efficiency. The test results shows that the measurement repeatability of the test device is superior to the artificial test device and common intelligent test device, and the assessed measurement uncertainty meets the requirements of the national supervision and inspection technical specifications.

1. Introduction

Energy efficiency labeling system is an important mandatory energy conservation management measures in China. With the in-depth implementation of the energy efficiency labeling system of gas water heaters, market regulators gradually increased the supervision and inspection of the energy efficiency labeling, which impels higher requirements for the energy efficiency testing devices to manufacturers and authoritative testing institutions, and accelerated the improvement and upgrading of the testing devices for energy efficiency [1]. Now, the traditional artificial test devices is widely used in the energy efficiency test in China, which simply assembling all kinds of testing sensors to a device, and calculate all parameters manually. This practice not only has a large workload, a long test period and inefficiency, but also bring human factors into measurement, which affects the accuracy and reliability of the measurement results. It will increase the judge risk of the government in energy efficiency supervision and inspection.

In recent years, with the rapid development of science and technology, the application of intelligent measurement and control technology in the measurement field is getting more mature. The traditional means relying on artificial measurement has been replaced gradually by efficient and intelligent measurement technology[2]. The development of high-precision intelligent test device for gas water heater energy efficiency, will solves the defects of slow test speed and inefficient for traditional device. It applies modern sensor technology, high reliability data acquisition card, solenoid valve control technology and stable industrial computer. It uses LabVIEW language, precise and reliable PID control technology and flow stability judgment algorithms to develop an efficient, accurate and intelligent test system for gas water heater energy efficiency, which can meet the test requirements of national standard GB6932 and national supervision and inspection specifications JF1261.9[3-4].
Through verification tests, the measurement repeatability and measurement uncertainty of the device is further evaluated.

2. General design scheme and main research contents

2.1 General design scheme
The research and development of high-precision intelligent test device for gas water heater energy efficiency, including the general scheme design, hardware circuit design, software development, system assembly and debugging of the test system [5-6]. As shown in Figure 1, the test device is mainly composed of industrial computer, data collector, PID controller, solenoid valve, gas and water pressure regulating valve, gas flow meter, water flow meter, gas pressure gauge, gas and water thermometer, etc. By collecting the parameters of gas temperature, gas pressure, gas flow, water flow, inlet and outlet water temperature, the industrial computer automatic integrated control according to the test methods, and then export results based on the specific algorithm.

![Figure 1. Structure of intelligent test device for gas water heater energy efficiency](image)

2.2 Hardware design
As shown in Figure 2, the system adopts industrial computer, data collector, PID controller and various sensors as the core hardware.
Figure 2. Hardware structure of test system

The data collector chooses Agilent 34980A, which has the characteristics of high resolution, fast response and high precision. It can collect the data of all sensors quickly and accurately, and realize the best matching of measurement and collection. The function of PID controller is to precisely control the water flow. The system adopts EUROTHERM 2404 high-precision PID controllers, which have the functions of self-tuning and PID gain meter. The current signal of flow meter is input to the controller, and the output of valve position is controlled by relay to the optimal control of flow.

The sensor is an important part of the device, the accuracy of the sensor is the key to ensure the accuracy of measurement. All kinds of sensors adopts high-quality brands at home and abroad, and the measurement technical specifications are superior to the mainstream products in the market. The technical specifications of the main sensors are shown in Table 1.

Table 1. Main sensor specifications

| Sensor name          | Range     | Accuracy     | Resolution   |
|----------------------|-----------|--------------|--------------|
| Temperature sensor   | 0～100 °C | ± 0.1 °C     | 0.05 °C      |
| Water Pressure sensor| 0～5 MPa  | ± 0.2%FS     | 1 kPa        |
| Gas Pressure sensor  | 0～20 kPa | ± 0.5%FS     | 1 Pa         |
| Liquid flowmeter     | 0～20 L/min | ± 0.5%     | 0.001 L/min  |
| Gas flowmeter        | 0～5000 L/h | ± 1.0%      | 50 mL        |

2.3 Software design

According to the industrial computer program, the test system software is designed to realize the functions of visual interface, data acquisition, serial communication, process control, parameter setting, data storage, etc. The main design includes: (1) Based on the consideration of high efficiency, convenience and friendly human-computer interface, the software is developed by LabVIEW language, which not only has a powerful visual component library, but also has the characteristics of flexible language and high execution efficiency. (2) The automatic control and measuring method of the test system applies the computer centralized and distributed measurement and control. The subordinate controller collects and displays the data, while the superior master computer analyzes and processes the data collected by the subordinate controller, and sends the set value instruction and data collection instruction to the subordinate controller. (3) Considering the subsequent data storage function, the built-in database can complete the data storage for test system, can directly access the specific data sources, and easy to operate the database with the provided database components. (4) The test system has a friendly human-computer interface, provides real-time graphic processing and intuitive simulation process control panel, which can monitor, record and store in real time.

3. Key Technologies of the device

3.1 Flow control

PID control is adopted for water heater outlet flow, which can monitor and control the operation status
of the system in real time. As shown in Figure 3, the controller adjusts the deviation between the measured value and the set value from the flow meter by proportion, differentiation and integration. If the actual flow does not meet the preset flow, the actuator will adjust according to the deviation until meet the preset requirements, so as to achieve the purpose of fast and accurate flow control.

![Diagram of the PID controller](image)

**Figure 3. Structure diagram of the PID controller**

The PID controllers have the functions of self-tuning and PID gain meter, which can automatically adjust the parameters to ensure better dynamic and static response of controlled flow, so as to meet the requirements of accurate control.

### 3.2 Test stability judgment

The objective influencing factors of accurate detection mainly come from outlet flow and temperature, while the stability of water temperature depends on the test water heater, not the device. Therefore, the stability control of flow is particularly critical, which directly affects the accuracy of test results. In order to ensure the stable operation in the test process, the system needs to judge the flow stability, ensure the flow to meet specific requirements in the stable phase. The algorithm of flow stability judgment, using the range value to evaluate the flow dispersion. Figure 4. Is the flowchart of stability judgment in stability stage.

![Flow chart of stability judgment in stability stage](image)

**Figure 4. Flow chart of stability judgment in stability stage**

The specific process for stability judgment is as follows: (1) The system should initialize the settings when entering the stable phase. Initialization set to: flow setting value is FSP, flow current value is FPV, stability deviation is DF, stable timer C0 set to zero, unstable timer C1 set to zero, stable timer setting is STime, unstable timer setting is KTime; (2) After initialization, collect the current flow value, calculate whether the deviation between the collected value and the set value meets the requirements. If the deviation meets the requirements, the stable timer C0 starts to accumulate until the stability judgment is successful, and then enter the test phase. Otherwise, the stability timer is set to zero, and the unstable timer C1 is accumulated to enter the unstable cycle.

### 4. Technical capability evaluation of the device

#### 4.1 Measurement repeatability of the device

The measurement repeatability is the key technical index to evaluate the stability of the test device [7]. In order to evaluate the measurement repeatability of the device, choose a gas water heater with stable
performance as the measurement sample, then the thermal efficiency is measured ten times continuously, the results were 94.5%, 94.5%, 94.4%, 94.8%, 94.4%, 94.4%, 94.6%, 94.5% and 94.3%.

According to the evaluation principle of uncertainty in JJF 1059.1-2012 Evaluation and Expression of Uncertainty in Measurement [8], the measurement repeatability of thermal efficiency is calculated by Bessel Formula, and the calculation formula is as follows:

\[
\phi(\eta) = \sqrt{\frac{\sum (\eta_i - \eta)^2}{n-1}}
\]

(1)

Where: \(\phi(\eta)\) is the repeatability of thermal efficiency measurement; \(\eta_i\) is the thermal efficiency value obtained from the i-th measurement; \(\eta\) is the average value of thermal efficiency obtained from the n-th measurement; \(n\) is the number of independent measurement.

Substitute the measurement results into the above formula, the repeatability of thermal efficiency measurement is 0.14%. According to the same test method, the repeatability is measured by traditional artificial test device and common intelligent test device, and the repeatability of ten consecutive measurements is 0.65% and 0.42%. It can be seen that the repeatability of the developed high-precision test device is much better than the artificial and the common intelligent test device.

4.2 Measurement uncertainty

Ensure the measurement accuracy of the device and continuous control of the measurement process, using uncertainty of measurement results as evaluation index. The evaluation of measurement uncertainty according to JJF 1059.1-2012 Evaluation and Expression of Uncertainty in Measurement and JJF1261.9 Rules of metrology testing for energy efficiency label of domestic gas instantaneous water heater and gas fired heating and hot water combi-boilers, the thermal efficiency is measured ten times and then the uncertainty is evaluated. Refer to the evaluation method in Appendix A of JJF1261.9, the measurement uncertainty components of thermal efficiency are shown in Table 2.

| Source of uncertainty | Measured value | Relative standard uncertainty | Distribution | Uncertainty component |
|-----------------------|----------------|-------------------------------|--------------|-----------------------|
| Repeatability         | 0.137%         | 0.137%                        | Normal       | 0.137%               |
| Water volume          | 12.255 kg      | 0.289%                        | Rectangle    | 0.289%               |
| Temperature difference| 40.0 K         | 0.204%                        | Rectangle    | 0.204%               |
| Gas temperature       | 297.8 K        | 0.019%                        | Rectangle    | 0.019%               |
| Gas flow              | 0.07 m³        | 0.289%                        | Rectangle    | 0.289%               |
| Calorific value of gas| 34.04 MJ/m³    | 0.577%                        | Rectangle    | 0.577%               |
| Pressure correction value| 99.009 kPa | 0.058%                        | Rectangle    | 0.058%               |

According to the composition principle of uncertainty in JJF 1059.1-2012 Evaluation and Expression of Uncertainty in Measurement, the relative standard uncertainty is 0.75%. When the confidence probability is 95%, the coverage factor \(k=2\), and the relative expanded uncertainty of thermal efficiency is 1.5%. The results meet the requirement of relative expanded uncertainty of thermal efficiency (1.6%) in national supervision and inspection technical specification (JJF1261.9).

5. Conclusion

The development of high-precision intelligent test device for gas water heater energy efficiency will greatly improve the technical level of energy efficiency test in gas water heater industry, provide accurate and reliable measurement data for authoritative testing institutions, and reduce the judge risk of government supervision and inspection. In conclusion, the research of high-precision intelligent test device for gas water heater energy efficiency can be summarized as follows:

(1) Based on modern sensor technology, high reliability data acquisition card, solenoid valve
control and stable industrial computer and other technical measures, develop an intelligent device which can meet the requirements of rapid and accurate test for gas water heater energy efficiency.

(2) The measurement technical specifications of sensors used in the device are superior to the technical level of mainstream products on the market; through test results analysis, the measurement repeatability of the device is superior to the artificial test device and common intelligent test device, and the measurement uncertainty of the device meets the requirements of the national supervision and inspection technical specifications, which will further reduce the judgment risk of supervision and inspection.

(3) The test system is developed with LabVIEW language, and adopts PID control technology and the algorithm of stability judgment to ensure more accurate test results.

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