



Research on the Computer Detection Algorithm and System of Steam Therapy Apparatus

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Abstract. In response to the lack of a unified parameter detection method and system for steam therapy apparatus, this study aims to establish a detection method for its key parameters and collect and store data through computers. By analyzing the principle of the equipment, the core parameters of steam temperature, time, over temperature alarm, and anti dry burning function have been clarified. A detection method was designed based on this, using a multi-channel temperature acquisition system to measure the temperature field inside the cabin, and using Bluetooth connection to upload temperature data to the computer. By calculating and analyzing the data collected by the computer, the results show that this method can effectively and reliably quantify and evaluate the various performance indicators of the equipment, with good data repeatability. The detection system constructed in this study provides feasible technical basis for solving industry pain points, has practical value in ensuring accurate equipment measurement values and clinical treatment safety, and lays the foundation for the formulation of relevant national metrology standard.

Keywords: Steam therapy apparatus, Store data, Temperature field, Calculating and analyzing

1 Introduction

With the rapid development of modern medical technology, various physical therapy equipment plays an increasingly important role in clinical rehabilitation, pain management and post-operative recovery. As an innovative medical device integrating traditional Chinese medicine principles and modern intelligent control technology^[1], the steam therapy apparatus heats liquid medicine into medicinal steam, which acts directly on the affected area. It has significant effects of warming meridians and dredging collaterals, dispelling wind and cold, promoting blood circulation and removing blood stasis, and is widely used in departments such as traditional Chinese medicine rehabilitation, orthopedics and gynecology. The accuracy of metrological parameters such as temperature and time of the intelligent temperature control unit in the core module of the steam therapy apparatus, as well as the over-temperature

alarm and dry-burning prevention functions, directly determine the reliability of curative effect and the safety of treatment.

At present, a large number of literature is available for research on acupuncture therapy devices. Hui-Jun Z focused on the influence of moxa stick ignition position on needle body and ambient temperature during warm acupuncture and moxibustion^[2]. The study used a high-precision infrared thermometer and conducted experiments with two ignition methods and four measurement positions. The temperature curve was plotted by taking the average of multiple measurements. The results showed that igniting the bottom of the moxa stick could reach the effective moxibustion temperature earlier, and there were significant differences in temperature peak and maintenance time at different ignition positions, providing experimental reference for temperature control and clinical operation standards of the acupuncture treatment device. In the paper [3], the biosafety of 304 stainless steel needle commonly used in warm acupuncture and moxibustion was studied. The experiment compared the temperature changes of 304 stainless steel needles with traditional gold alloy needles, and also tested indicators such as pH value, heavy metal content, cytotoxicity, and hemolysis reaction of silicone coated, salicylic acid coated, and uncoated 304 stainless steel needles. The results showed that all safety indicators of 304 stainless steel needles met the standards. Although their temperature stability was slightly inferior to that of gold alloy needles, they fully met the biological safety requirements for fumigation therapy. The issue of temperature safety has been considered both in [2] and [3], but unfortunately, there are no relevant solutions. The authors in [4] conducted research on the safety performance evaluation criteria of electronic needle therapy devices, combined with core indicators such as heating stability, electromagnetic compatibility, and biocompatibility, and constructed a scientific evaluation system, providing a standardized reference framework for the research and development, production, and market access of needle therapy devices.

On the other hand, with the rapid development of computer technology, it is gradually replacing the traditional method of measuring temperature with thermometers. Being able to use computers to display real-time temperature changes and efficiently and quickly analyze data such as temperature uniformity and fluctuation. The author in paper [5] proposes a calibration free temperature measurement method based on photo induced thermoelastic spectroscopy. Through the steady-state and transient responses of quartz tuning forks, the errors of all four measurement methods are less than 4%. The optimal solution can shorten the measurement cycle to 4 seconds and adapt to harsh temperature measurement environments. A multispectral temperature measurement method based on the grey body assumption and color temperature difference was proposed in [6]. Constructing an equation system based on Wien's displacement law and solving it using the least squares method, the temperature measurement error is less than 1%, which has been verified in gas discharge temperature measurement. In order to combine cutting-edge technology, the author uses cholesteric liquid crystal elastomers and machine vision to construct two deep learning models^[7]. It can accurately output temperature through material color changes and achieve large-scale two-dimensional temperature distribution visualization, making it a low-cost and efficient temperature measurement solution. Although there is a large amount of computer technology

available for collecting and storing temperature data, the focus is rarely on steam therapy apparatus.

In addition, there is a lack of testing methods for key parameters of steam therapy apparatus in China, and there are no corresponding metrological verification regulations or calibration standards. This has led to various levels of metrology technology institutions, medical equipment departments, and third-party testing institutions having no rules to follow and different methods to carry out relevant calibration. Some institutions only use ordinary thermometers for rough measurements, ignoring the complex steam environment and uneven temperature distribution inside the equipment. Some focus on the detection of electrical safety indicators, while neglecting their output energy value as therapeutic equipment^[8]. According to the National Medical Device Adverse Event Monitoring System, 23.6% of equipment failure cases in 2023 are directly related to inaccurate temperature control or abnormal steam concentration^[9-10], highlighting the urgency of building a metrological calibration system.

Therefore, establishing a scientific, reliable, and operable detection method for steam therapy apparatus has important theoretical significance and urgent practical needs. The purpose of this study is to deeply analyze the working principle of steam therapy apparatus and the key parameters that affect its efficacy, and design a dedicated detection method and computer system. The focus is on exploring the collection of temperature, time, and other related data at multiple points in the treatment cabin through computers, calculating and analyzing them to form a complete set of detection techniques, and contributing to the accurate and unified measurement of fumigation treatment and the quality and safety of clinical medical care.

2 Working Principle and Metrological Characteristics of Key Parameters of Steam Therapy Apparatus

2.1 Structure and Working Principle

Classified by treatment method, Steam therapy apparatus is divided into open-type and closed-type. The closed-type steam therapy apparatus is further divided into local treatment and whole-body treatment types, as shown in Figure 1. The steam therapy apparatus is composed of an intelligent control system, a steam generation module, a steam delivery system and a safety monitoring unit. According to the preset treatment parameters (temperature, time, mode), the intelligent control system heats the traditional Chinese medicine liquid to (45-65) °C and atomizes it into steam, realizing targeted therapy through transdermal absorption of drug ions. In the core functional modules, the temperature control accuracy and time response characteristics of the steam generation module directly determine the thermal decomposition efficiency of the effective components of the drug. The coordinated operation of these key components makes the accuracy of the equipment's metrological parameters a technical prerequisite for ensuring clinical efficacy and safety.

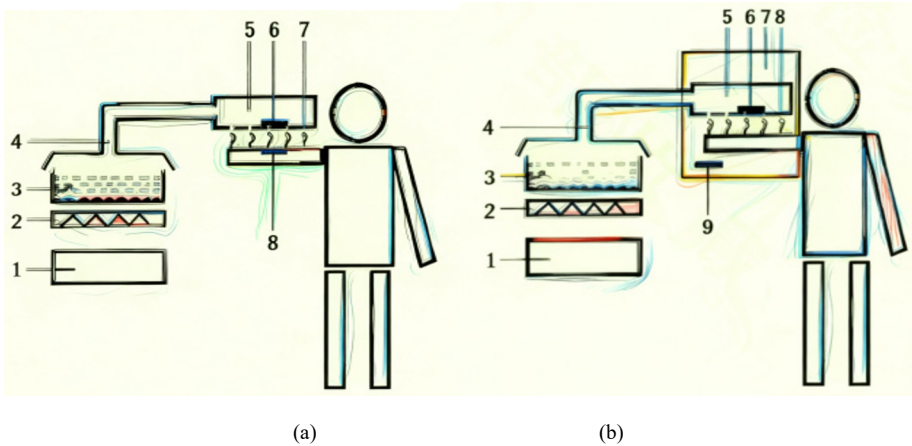


Fig. 1. (a)Open-type therapy apparatus. (b)Closed-type local therapy apparatus (1-control unit;2-heating unit;3-precooking container;4-Precooking container;5-steam output unit;6-steam outlet temperature sensing unit;7-treatment cabin;8-steam outlet;9-temperature sensing unit inside the treatment cabin)

2.2 Metrological Characteristics Requirements for Key Parameters

Through the research on the structure and key technical parameters of different types of Steam therapy apparatus, combined with relevant technical standards, this paper summarizes the following key metrological parameters.

- **Steam temperature:** The open-type steam therapy apparatus can display the skin temperature in real time, and the accuracy of the skin temperature sensor is a prerequisite for the safety of patients' treatment. The temperature error, temperature uniformity and temperature stability in the cabin of the closed-type steam therapy apparatus affect the thermal absorption efficiency of drugs and treatment safety. Therefore, it is necessary to calibrate the temperature control module of the steam therapy apparatus.
- **Steam time:** The efficacy of traditional Chinese medicine steam is directly related to the amount of transdermal drug absorption, which is affected by the time-temperature integral. A tolerance of ± 30 seconds can control the fluctuation range of the total heat energy in a single treatment within 1.67% (taking a 30-minute treatment as an example), avoiding insufficient or excessive absorption of effective components due to time deviation. Therefore, in response to the demand for precise treatment in traditional Chinese medicine, the steam time error should be calibrated.
- **Over-temperature alarm function and dry-burning prevention function:** These functions are requirements for the electrical safety protection of the Steam therapy apparatus.

The requirements for metrological characteristics are summarized in Table 1.

Table 1. Measurement requirements

Parameters	Closed-Type Therapy Apparatus	Open-type therapy apparatus
Temperature indication error	MPE: $\pm 3^{\circ}\text{C}$	MPE: $\pm 1^{\circ}\text{C}$
Temperature uniformity	$\leq 3^{\circ}\text{C}$	Not applicable
Temperature stability	$\leq 3^{\circ}\text{C}$	Not applicable
Fumigation time error	MPE: $\pm 30\text{s}$ (for both types)	MPE: $\pm 30\text{s}$ (for both types)
Over-Temperature alarm function	Not applicable	Alarm sound $\geq 60\text{dB}$ (A)
Dry-Heating prevention function	Shall be equipped	Shall be equipped

2.3 Equipment Required for Testing

The equipment required for testing is as follows:

- (1) Distributed temperature sensor array: spatial resolution ≤ 5 cm, measurement uncertainty $\leq 0.3^{\circ}\text{C}$ ($k=2$), sampling frequency ≥ 1 Hz;
- (2) Standard sound level meter;
- (3) Computer detection system, as shown in Figure 2.



Fig. 2. Computer detection system

2.4 Calibration Items and Methods

The calibration items of the steam therapy apparatus include temperature indication error, temperature uniformity, temperature stability, time error, over-temperature alarm function and dry-burning prevention function. The equipment operates under no-load condition at rated voltage for 30 minutes to eliminate the influence of initial thermal inertia. Distilled water is used as the liquid in calibration.

2.4.1 Steam Temperature.

(1) Open-type therapy apparatus: For the therapy apparatus with a contact temperature sensing unit, put the temperature sensing unit into a constant temperature water

tank, set the water tank temperature to 37°C/43°C/45°C, place the measured temperature sensing unit and the standard thermometer in the constant temperature water tank at the same time, and calculate the indication error between the displayed temperature and the standard thermometer. For the therapy apparatus with an infrared temperature sensing unit, align the infrared temperature sensing unit with the surface black body, with the calibration distance being the safety distance specified in the accompanying document of the therapy apparatus, set the surface black body temperature to 37°C/43°C/45°C, and calculate the indication error between the displayed temperature and the standard black body temperature Δt using Formula (1).

$$\Delta t = t - t_s \quad (1)$$

In(1): t -Display value of the therapy apparatus, °C;

t_s - Indication value of the standard thermometer or standard black body, °C.

(2) Closed-type therapy apparatus: Set the maximum temperature, intermediate temperature and minimum temperature respectively according to the temperature specified in the accompanying document of the therapy apparatus. Arrange n measurement points evenly on the patient contact surface ($n \geq 5$), and measure the steam temperature with a distributed temperature sensor array.

Temperature indication error: In the calibration of each temperature point, take the difference between the temperature set value and the average value of the temperatures at the above n measurement points as the temperature indication error Δt .

$$\Delta t = t_0 - \frac{1}{n} \sum_{i=1}^n t_i \quad (2)$$

In(2): t_0 -Temperature set value of the therapy apparatus: 37°C/43°C/45°C;

t_i -Temperature value at n point, °C.

Temperature uniformity: In the calibration of each temperature point, take the difference between the maximum and minimum temperatures among the above n measurement points as the temperature uniformity of the steam therapy apparatus Δt_u .

$$\Delta t_u = t_{\max} - t_{\min} \quad (3)$$

In(3): t_{\max} -Maximum temperature of the n measurement points, °C;

t_{\min} -Minimum temperature of the n measurement points, °C.

Temperature stability: After the therapy apparatus operates stably, collect data from the n calibration points every 5 minutes, repeat the operation 5 times, and calculate the difference between the maximum and minimum values of the 5 averages as the temperature stability of the steam therapy apparatus Δt_f .

$$\bar{t}_j = \frac{1}{n} \sum_{i=1}^n t_{ji}, \Delta t_f = [\bar{t}_j]_{\max} - [\bar{t}_j]_{\min} \quad (4)$$

In (4): t_{ji} -Temperature measurement value of the therapy apparatus at the j -th minute (5min, 10min, 15min, 20min, 25min) at the i -th point, °C;

\bar{t}_j - Average temperature value of the n measurement points of the therapy apparatus at the j -th minute, °C.

2.4.2 Verification of Over-Temperature Alarm Function and Dry-Burning Prevention Function.

For open-type therapy apparatus with contact temperature sensing unit: Put the temperature sensing unit of the therapy apparatus into a constant temperature water tank, place the measured temperature sensing unit and the standard thermometer in the constant temperature water tank at the same time, heat the water tank. When the temperature displayed by the standard thermometer reaches 45°C, the therapy apparatus shall continuously emit a sound prompt. Keep the water tank temperature constant, and the therapy apparatus shall stop heating before the continuous sound prompt lasts for 10 minutes.

For open-type therapy apparatus with infrared temperature sensing unit: Align the infrared temperature sensing unit with the surface black body, with the test distance being the distance specified in the accompanying document. Set the surface black body temperature to 40°C, and after the temperature is stable, set the surface black body temperature to 45°C. When the temperature displayed by the surface black body reaches 45°C, the therapy apparatus shall continuously emit a sound prompt and stop heating before the continuous sound prompt lasts for 10 minutes. Place the therapy apparatus in an environment where the background noise is 10 dB lower than the sound pressure level of the measuring point, trigger the alarm sound prompt of the therapy apparatus, and measure at 1meter in front of, behind, left of and right of the therapy apparatus to get the decibel value of the prompt sound.

Verification of dry-burning prevention function: It is to check whether the protection mechanism of the steam therapy apparatus can be triggered correctly when the liquid medicine or water level in the steam generator is lower than the safety limit. During verification, operate the therapy apparatus in a normal initial state. After it enters a stable heating state, empty the liquid in the cavity through its designed drain valve or with a special tool to simulate the "dry-burning" state. At the same time, observe the working state of the heater and the human-machine interface or sound-light alarm system. The therapy apparatus shall stop heating within a specified time after the liquid is emptied (refer to the accompanying manual), and this process shall be repeated three times.

3 Result

In this article, three commonly used fumigation treatment devices in domestic medical institutions were selected, namely DK-701 from Shijiazhuang Dukang Medical Equipment Co., Ltd., GJT-XZ-III from Sichuan Zocheng Technology Co., Ltd., and QLY-E from Jinan Huale Medical Equipment Co., Ltd (represented by A, B, C). Firstly, test the anti dry burn function of each instrument. The steam generator does not add liquid, and the treatment time is set to 25 minutes. Turn on the instrument, and each model of instrument can automatically stop heating with a prompt message. Next, follow the steps in section 2.4.2 to test the over temperature alarm function. Set the temperature of the therapeutic device to 43 °C, and put the temperature sensing unit of the therapy apparatus into a constant temperature water tank. Heat the water temperature to 50°C

and wait for the alarm sound to sound a measurement prompt sound. The decibel values of the prompt sound are 74dB, 78dB, and 82dB, which meet the requirement that the prompt sound should not be less than 60dB.

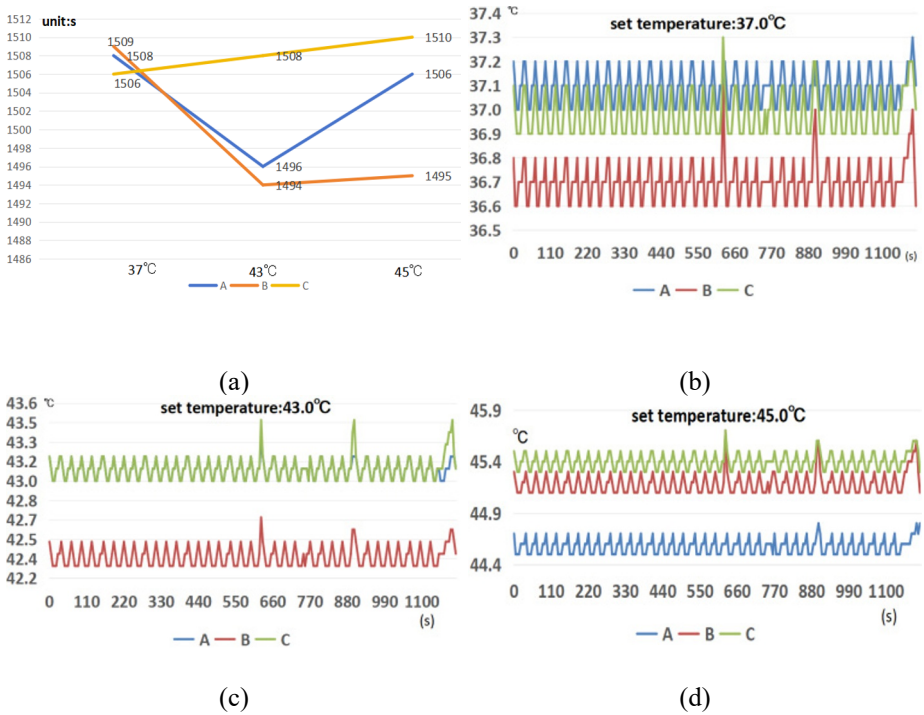


Fig. 3. (a) Time measurement results. (b), (c) and (d) Temperature measurement results.

In this paper, we use a temperature testing system model Pro6X. The calibration points for temperature selection are 37°C, 43°C, and 45°C. At each calibration point, set the treatment time to 25 minutes, add sufficient distilled water, and turn on the instrument for treatment. Before turning on the treatment device, we evenly distribute temperature probes in the device. The computer monitors and stores real-time temperature and time parameters inside the temperature chamber which are shown in Figure 3.

Calculate based on temperature data and the formula in Section 2.4.1 and the results obtained are shown in Table 2. From the following calculation results, it can be seen that the temperature and time parameters of the acupuncture treatment device meet the requirements in Table 1, which verifies the feasibility of the proposed measurement method.

Currently, there are also a few temperature measurements for steam therapy apparatus on the market, but they only measure the center point position. In future testing, this article can be used as a reference to unify the measurement points based on the space size of the steam therapy apparatus, and use a high-precision temperature measurement system for temperature detection.

Table 2. Results of parameter error

Equipment Number	Time error(s)			Temperature indication error(°C)			Temperature uniformity(°C)			Temperature stability(°C)		
	37°C	43°C	45°C	37°C	43°C	45°C	37°C	43°C	45°C	37°C	43°C	45°C
A	8	-4	6	-0.1	-0.1	0.4	0.3	0.3	0.3	0.4	0.5	0.5
B	9	-6	-5	0.3	0.6	-0.2	0.5	0.4	0.6	0.6	0.6	0.8
C	6	8	10	0.0	-0.1	-0.4	0.4	0.5	0.4	0.5	0.6	0.6

4 Conclusion and Prospect

By analyzing the structure and principle of the steam therapy apparatus, this study clarifies that steam temperature, steam time error, over-temperature alarm function and dry-burning prevention function are the core key parameters. Based on these parameters, this study designed and proposed corresponding calibration methods and operating procedures, and designed a computer detection system to analyze the data collected by the computer through experiments. The experimental results show that the calibration method proposed in this study can realize accurate, multi-point and real-time measurement of the temperature field in the treatment cabin of the steam therapy apparatus, and the obtained data effectively solves the problem of incomplete measurement by traditional methods. The designed calibration method for time error is easy to operate with good result repeatability. The verification methods for over-temperature alarm function and dry-burning prevention function are effective and feasible, which can scientifically determine whether the performance of the safety protection device meets the clinical safety requirements.

In conclusion, the complete set of calibration methods for steam therapy apparatus constructed in this study has good feasibility and effectiveness. This method not only provides clear technical basis and operation guidelines for metrological technology institutions, equipment departments of medical institutions and relevant testing laboratories, but also lays a solid metrological foundation for ensuring the accurate quantity value, reliable curative effect and safe use of steam therapy apparatus.

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