The Study of a Portable Precision Air Enclosure for Preserving Standard Resistor

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Abstract. A novel portable precision air enclosure was designed in this paper. Orthogonalization of the coefficients matrix to decouple the all parts of the control system was attained in theory and heating wires were wound on the surface of the aluminum chamber evenly in construction. Foam plastic was placed between outer and aluminum chamber as thermal insulation. The inner space is 300 mm×250 mm×300 mm, where can fit one SR 102 type resistor or two Tinsley 5685 type resistors. The total weight of the enclosure is about 25kg, which is still a portable one. Its outstanding feature is the temperature difference between top and bottom was offset. Experiment result shows that the monthly inner temperature homogeneity and stability of the enclosure are within 2 mK.

1. Introduction

Based on the Quantum Hall Resistance (QHR) and Cryogenic Current Comparator (CCC) technique, many national laboratories have established the resistance standard systems with uncertainty of a few parts in 10\textsuperscript{-9} or less. When disseminating QHR value to standard resistor, especially in the case of inter-comparison between different countries, it is of vital importance to retain the surroundings’ temperature of the resistor highly stable and homogeneous. In practice, a portable air enclosure with high precision is an adequate apparatus for this purpose.

The portable air enclosure with high stability was firstly developed to maintain standard cells [1-4]. Its highest stability published reached 10 µC/°C. But the size of inner space of these enclosures is only of several cubic inches, which is only suitable for the standard cell whose size is very small. Nowadays the standard resistor not only occupies more space but consists of several elements with slightly different temperature coefficients for the purpose of better total temperature performance. Therefore the total temperature curve of resistor is found by combination. If the inner temperature of enclosure is inhomogeneous, the total temperature curve by combination will be changed with temperature variation. As a result, the temperature performance of the standard resistor will likewise be degraded. Thereby, we laid a strong emphasis on the counterbalance of temperature difference in such a large inner space in this paper.

2. The principle and key technology

The structure of enclosure is shown as figure 1. The outer dimension is 500×400×460mm, and the inner chamber, whose size is 300mm×250mm×300mm, is composed of 40mm aluminum sheets. Two
Tinsley 5685 type resistors can be placed there. Twisted pair heating wires is wound evenly on the surface of the aluminum chamber, which is preventing effect of external magnetic field. These heating wires are wound tightly on the surface of the aluminum chamber with spiral shape in order to supply better thermal match that will achieve better controlling-temperature result. Foam plastic was placed between outer and aluminum chamber as thermal insulation, whose thermal conductivity is 0.095 kilocalorie/hour•°C, corresponding to 9°C temperature rise per one watt heating power.

Figure 1. The structure of the enclosure.

Experiments’ result shows that: the warmer air in the inner space of the enclosure mostly gives rise to temperature inhomogeneity. The temperature of top is slightly higher than that of bottom, namely there is temperature gradient in the vertical direction and hardly any temperature gradient in the level direction of enclosure. Therefore the heaters are divided into three parts, including the top, the bottom and the wall shown as figure 2. All the heaters are put the same current, acting as the principal current; the top and the bottom heater are again put adjustable lower current, acting as the fine tuning current to offset the temperature gradient. These two fine tuning currents must be supplied by independent circuits to withhold circuits’ interference. However these two independent circuits must be connected at a point to assure a common reference point, which will be helpful for preventing the effect of floating-ground.

Figure 2. The structure of the heater.

Because of the temperature gradient arising in the vertical direction, there are at least two control circuits in the system. One control circuit named principal control circuit is designed to regulate and stabilize the total temperature of the inner chamber, which is shown as figure 3; and other circuit named fine tuning control circuit is designed to eliminate the temperature gradient between the top and
the bottom, which is shown as figure 4. It has been proved by the previous research that two control circuits in the system can be decoupled by orthogonalization of the controlling coefficient matrix. Two control circuits are operated independently and the control system is simplified. Therefore it is very easy to adjust these two control system [5].

![Figure 3. Schematic diagram of principal control circuit.](image1)
![Figure 4. Schematic diagram of fine tuning control circuit.](image2)

The operation of offsetting the temperature difference of enclosure does not influence the total heating power, proved as following:

Considering the symmetry of the enclosure structure, we may suppose $\delta I$ and $-\delta I$ are the currents of decreasing the temperature difference between the top and bottom. So the consumed power of the each heater of the enclosure is:

$$P_t = (I-\delta I)^2 R_t$$  \hspace{1cm} (1)
$$P_m = I^2 R_m$$ \hspace{1cm} (2)
$$P_b = (I+\delta I)^2 R_b$$ \hspace{1cm} (3)
$$P_{total} = P_t + P_m + P_b$$ \hspace{1cm} (4)

In fact, $\delta I$ is by far smaller than $I$. In other words, $\delta I$ is little increment of $I$. Furthermore because of $R_t=R_b$, in the first-order approximation case, the power is:

$$P_t = I^2 R_t - 2\delta I R_t$$ \hspace{1cm} (5)
$$P_m = I^2 R_m$$ \hspace{1cm} (6)
$$P_b = I^2 R_b + 2\delta I R_b$$ \hspace{1cm} (7)
$$P_{total} = P_t + P_m + P_b = I^2(R_t + R_m + R_b)$$ \hspace{1cm} (8)

From equation (5) and equation (7), $P_b$ will increase with line increase of $\delta I$ while $P_t$ will decrease with line increase of $\delta I$. The change of $\delta I$ will alter the temperature difference between top and bottom. Even though $\delta I$ is not zero, $P_{total}$ will almost be unchanged from equation (8). So the adjustment of $I$ will determine the inner temperature of enclosure while the adjustment of $\delta I$ will only regulate the temperature difference between the top and bottom and hardly change the total heating power. In other words, these two adjust operation are independent each other for power.

To become a portable one, the enclosure should be designed to equip with a rechargeable battery as the power supply during transportation, which would be helpful for sustaining the temperature stability of enclosure.

3. The experiment result

Using three thermistors that had been calibrated, we measured the temperature of three controlling points [6]: two thermistors were mounted on the top and bottom of enclosure respectively, Which would measure and offset the temperature difference by fine tuning control circuit shown as figure 4; another one were mounted in the middle hole of standard resistor, which would display the average temperature of inner chamber of the enclosure.

After one month observation that was not discontinuous the temperature variation curve is shown as figure 5. We can come to safely a conclusion that even though the ambient temperature variation is about 1.5°C, the temperature stability of model machine has reached 2mK. It is very excellent of the
ability of withstanding ambient temperature variation and sustaining the long-time temperature stability of enclosure.

![Figure 5. Monthly (long-time) temperature variation curve of enclosure.](image)

4. Conclusion
A novel portable precision air enclosure is devised in this paper, whose excellence is high homogeneity and stability when the inner chamber is enlarged. The elaborated air enclosure have many strongpoints, including conveniently carried, easily operated, strong ability of withstanding ambient temperature, fine stability and so on. Its monthly temperature stability is within 2 mK, which will be useful for the maintenance of resistance standard and for the comparison between different laboratories.

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