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An Innovative Approach to Addressing the Waterproofing Challenges of NTC Temperature Sensors

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Abstract

Aiming at the waterproofness problem of NTC temperature sensor, a new method was proposed to coat NTC thermistor with double-layer Teflon heat shrinkable tube. Different sample groups were made of electric boiling experiments. The difference between the method and the conventional epoxy-resin-coated NTC thermistor was compared. The results show that the temperature sensor made by this method has excellent waterproof performance and meets the expectation.

Keywords: double-layer Teflon heat shrinkable tube, electric boiling, waterproof performance

1. Introduction

Reference (Xun Yanfang, 2014) proposed a temperature sensor that uses the law of temperature change of various physical properties of materials to convert temperature into a usable output signal. Temperature sensors are the core part of temperature measuring instruments and come in a wide variety of varieties. According to different measurement methods, temperature sensors are divided into two categories: contact type and non-contact type. NTC (Wang L, Liu Y & Peng S X., 2017) thermistor temperature sensor (NTC: Negative Temperature Coefficient Thermistor) belongs to the contact type and has many applications, such as household appliances, electronic products, and various automobiles. Among them, NTC thermistor is the core component of the temperature sensor and can efficiently measure the temperature of various objects to prevent short circuits caused by overheating of electrical appliances. The wide range of applications of NTC thermistor temperature sensors requires them to be in a high humidity environment for a long time. Therefore, the temperature sensor (Yu Y & Zhang Y H., 2023) needs to meet strict waterproof requirements to prevent water vapor from entering the temperature sensor and causing abnormal resistance of the NTC thermistor.

In order to improve the waterproof performance of temperature sensors, the industry generally adopts epoxy resin coating to resist the intrusion of water vapor, that is, encapsulating NTC thermistors with epoxy resin. This method can resist water vapor to a certain extent, but it cannot meet more stringent waterproof requirements. In addition, the process of encapsulating NTC thermistors with epoxy resin is relatively complicated, requiring ingredients → coating (1 or 2 times) → curing (curing time is generally not less than 30 minutes), and the process cost is relatively high.

This paper proposes a method of encapsulating NTC thermistors with two layers of Teflon heat shrink tubes (Liu Z M & Peng R L., 2015). The inner layer of the two layers of Teflon heat shrink tubes is a molten layer made of FEP (perfluoroethylene propylene copolymer), and the outer layer is an insulating layer made of PTFE (polytetrafluoroethylene). This method enables the waterproof performance of the temperature sensor to meet the expected requirements. Take an NTC thermistor temperature sensor for a PTC heater of a new energy vehicle air conditioner as an example.

2. Theoretical Analysis

2.1 Potential Failure Path of Waterproofing of Temperature Sensor

The NTC thermistor temperature sensor used in the PTC heater of the air conditioner of new energy vehicles in the prior art is mainly composed of a housing (Sun Y & Huang W B., 2020), an NTC thermistor, wires, and epoxy resin (Li X R, Zheng T, Wang X D, et al., 2024). Among them, the housing is used to fix the position of the NTC thermistor and is connected to the application end; the wire is used to connect the NTC thermistor and transmit signals, and the material is FEP (Zhang L J & Yang H J., 2021). As shown in Figure 1.

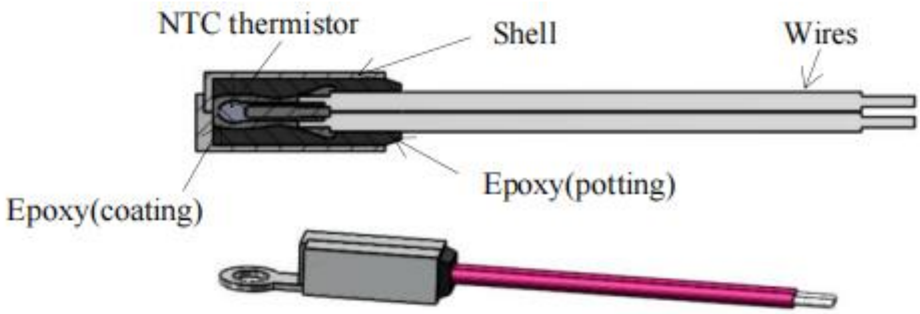


Figure 1. Diagram of NTC sensor structure

Potential paths for water vapor intrusion are shown in Figure 2. Path 1: Blue dashed line, gap between housing and epoxy resin (potting) → epoxy resin (potting) → epoxy resin (coating) → NTC thermistor

Path 2: Yellow dashed line, gap between wire and epoxy resin → epoxy resin (potting) → epoxy resin (coating) → NTC thermistor

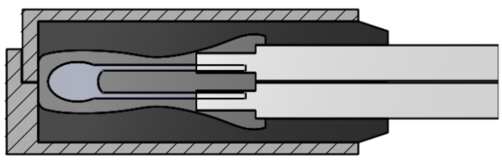


Figure 2. Diagram of moisture intrusion potential channel

From the above potential water vapor intrusion paths, it can be seen that the NTC thermistor relies on the waterproof performance of epoxy resin (coating) to resist water vapor intrusion corrosion.

2.2 Waterproof Performance of Materials

The water absorption rate of epoxy resin after curing (100°C, 100 hours) of epoxy resin manufacturers at home and abroad is generally 0.1~1.0%.

The specifications of Teflon (FEP, PTFE) (Hou W F, Zeng D Y & Ao Y Q., 2023) from domestic and foreign manufacturers state that the water absorption rate is less than 0.01%, which means that it absorbs almost no water.

Reference (Jin Qi, Liu Wenbin, Liu Yan, et al., 2022) proposes that after polytetrafluoroethylene (PTFE) is stretched, it forms a mesh structure in the three-dimensional direction, and the micropore diameter is maintained at 0.3~1.2μm, which is much smaller than the diameter of water droplets (dew form: 100μm; light rain form: 500μm; moderate rain form: 2000μm). It has excellent water barrier properties and even the smallest mist cannot pass through.

It can be inferred that the water absorption rate of Teflon (FEP, PTFE) is significantly lower than that of epoxy resin.

3. Waterproof Design of Temperature Sensor

3.1 Waterproof Structure Design of Temperature Sensor

Based on the potential water vapor intrusion path analyzed in 1.1 and the waterproof performance analysis of materials in 1.2, the waterproof design focuses on the optimization of the NTC thermistor coating structure. Reference (Ding Xiao, Ma Weiwei, Wei Wenbiao, et al., 2022) proposed to use two layers of Teflon heat shrink tubing to replace epoxy resin to encapsulate the NTC thermistor. Therefore, the waterproof structure design of the NTC thermistor temperature sensor for PTC heater includes: shell, NTC thermistor, wire (material FEP), two layers of Teflon heat shrink tubing (inner tube FEP, outer tube PTFE), and epoxy resin.

The NTC thermistor is connected to the wire to convert the temperature signal into a usable signal output. The two layers of Teflon heat shrink tubing encapsulate the connected NTC thermistor and then shrink to form a dense waterproof layer to enhance the waterproof performance of the temperature sensor. The waterproof layer formed by heat shrinkage will be fixed in the shell through the curing of the epoxy resin (Pi Q Q, Wang D X, Li T, et al., 2024). The shell is fixed to the application end. As shown in Figure 3 below.

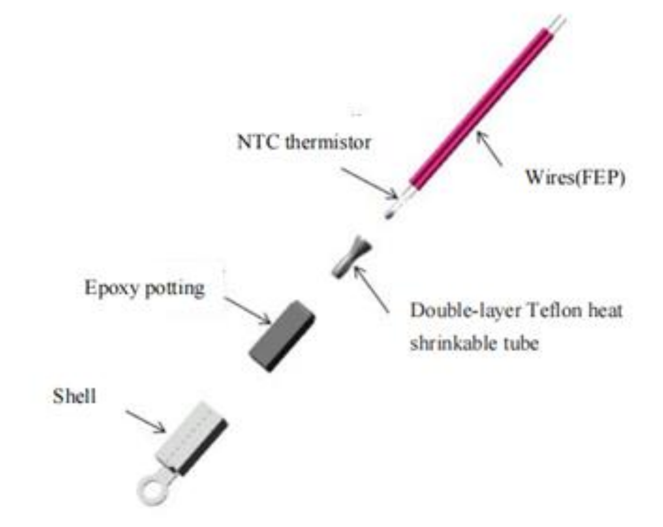


Figure 3. Explosion diagram of current NTC sensor design

3.2 Waterproof Structure Process Design of Temperature Sensor

The NTC thermistor and two layers of Teflon are cut to appropriate sizes. The NTC thermistor and the wire are connected by laser welding (Cong J H, Gao J Y, Zhou S, et al., 2024). After welding, the NTC thermistor is completely encapsulated with a double-layer Teflon heat shrink tube and then heat-shrunk. The inner tube FEP is exposed 2~3mm longer than the outer tube PTFE, so that the inner tube FEP can completely encapsulate the thermistor and the wire after melting. Subsequently, the epoxy resin is poured into the shell and cured to complete the manufacture of the temperature sensor. As shown in Figure 4 below.

Laser welding → Double-layer Teflon tube heat shrink packaging → Epoxy resin potting fixed shell

Figure 4. Working process diagram

4. Experimental Verification

4.1 Experimental Plan

The experiment was divided into three groups. According to the different coating structures of NTC thermistors, the current design uses two layers of Teflon heat shrink tubing for heat shrink coating, and epoxy resin coating and curing to fix it in the shell. Comparison group 1 only uses two layers of Teflon heat shrink tubing for heat shrink coating, without epoxy resin and shell. Comparison group 2 uses the common design in the industry, epoxy resin coating and curing, epoxy resin coating and curing to fix it in the shell. All other components are consistent and from the same batch. The number of experiments is based on the requirements of literature (Automotive Electronics Council, 2010), as shown in Table 1.

Table 1. Experimental sample plan

Sample group	Sample Description	Test Quantity (pcs)	Sample Image
Current design	Two layers of Teflon heat shrink package thermistor + shell	77	
Comparison group 1	Only two layers of Teflon heat shrink wrap thermistor	77	
Comparison group 2	Epoxy coated Thermistor	77	

4.2 Experimental Equipment

The temperature sensor waterproofing test equipment used in this experiment is a constant temperature water bath (HH600) and a DC power supply (SPS-C1203S). The constant temperature water bath (HH600) can provide an adjustable temperature of 30~100℃, and the DC power supply (SPS-C1203S) can provide an output of 120V 3A.

4.3 Experimental Method

The three groups of temperature sensors were immersed in a constant temperature water bath (HH600) and a boiling water experiment was conducted (Yu L, Yan L, Tang W, et al., 2021). The water temperature was maintained at 100℃, and a DC power supply (SPS-C1203S) was used to provide 5V DC. After 1000 hours, the resistance R25 change rate was tested to be no more than ±3%. This experimental method is the most stringent of the standard AEC-Q200 waterproofing test items proposed in reference (Automotive Electronics Council, 2010), such as IPX8, high temperature and high humidity test, etc. The test circuit diagram proposed in reference (Automotive Electronics Council, 2010) is shown in Figure 5 below.

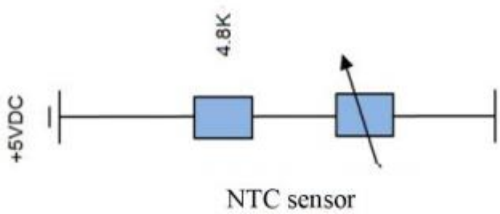
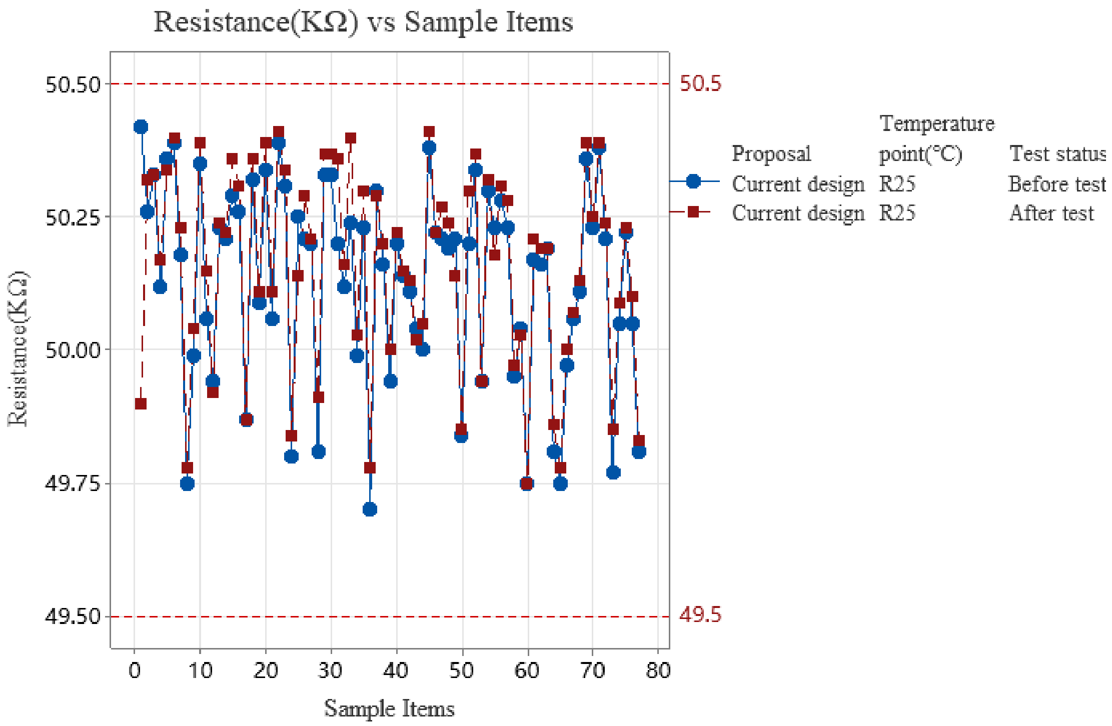


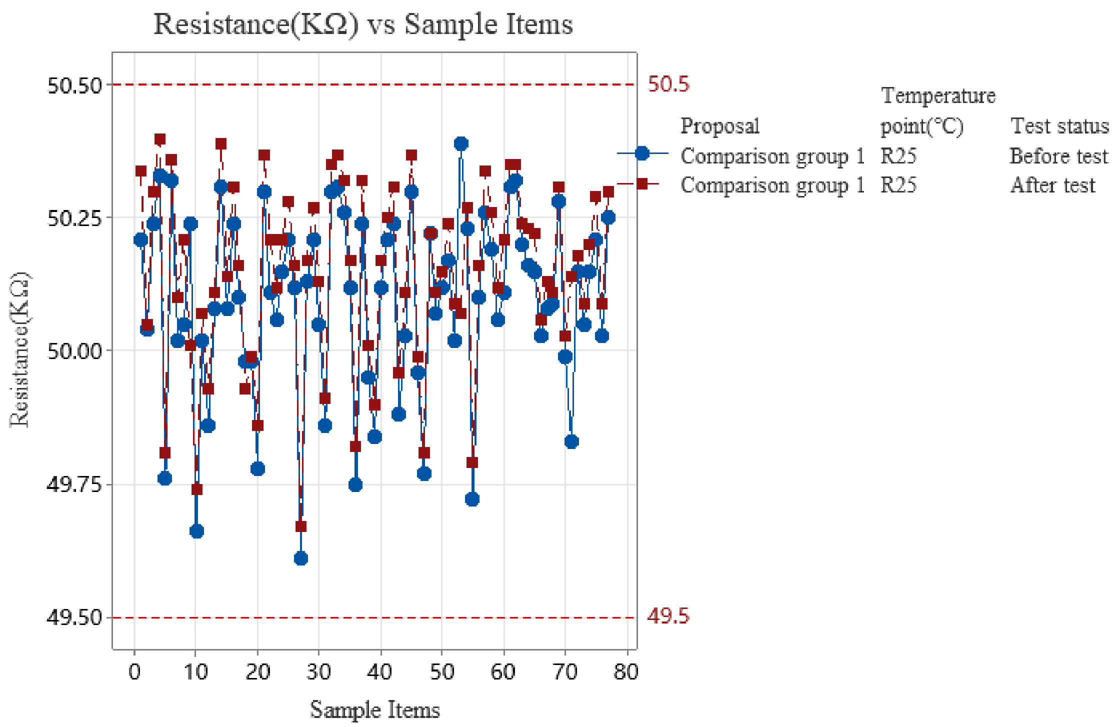
Figure 5. Diagram of NTC sensor test circuit

4.4 Experimental Results

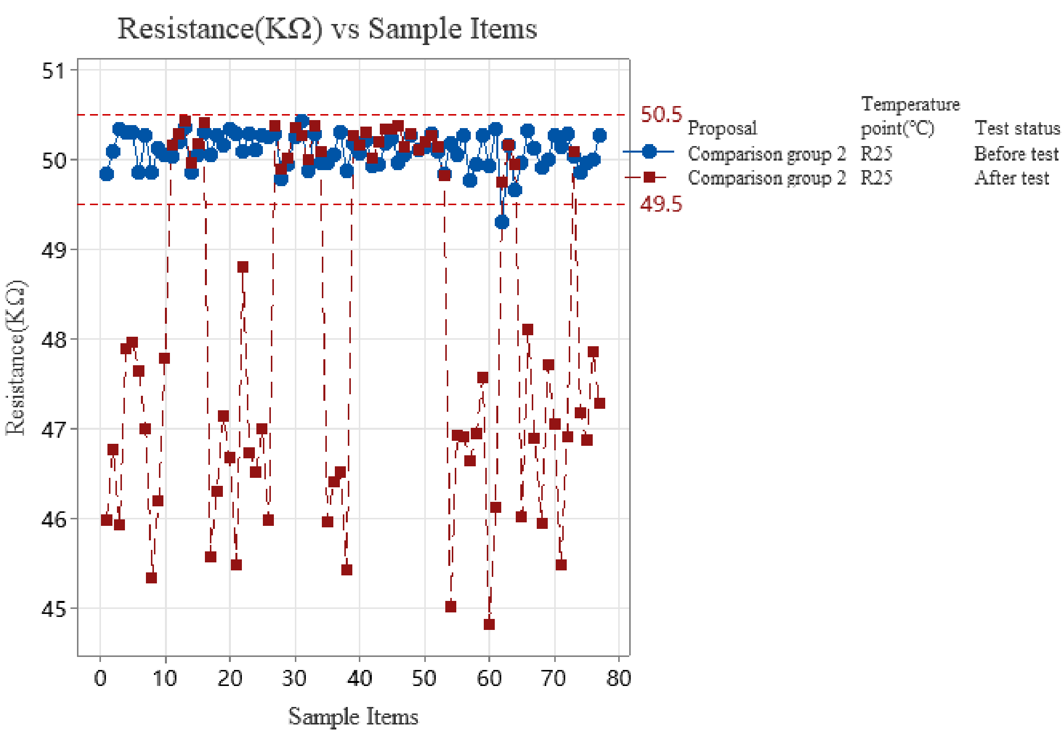
The resistance value specification range of the three schemes before the experiment is the same as R25: 49.5KΩ~50.5KΩ. After 1000 hours of electric boiling test, the R25 resistance of the current design and the comparison group 1 scheme are within the specification range, and the change rate of R25 resistance (△R/R) is less than ±3%, and the change trend is similar, which meets the experimental requirements. However, after 1000 hours of electric boiling test, most of the R25 resistance of the comparison group 2 (epoxy resin encapsulated thermistor) scheme exceeds the specification range, and the change rate of R25 resistance exceeds ±3%, which does not meet the experimental requirements. As shown in Figure 6 below.



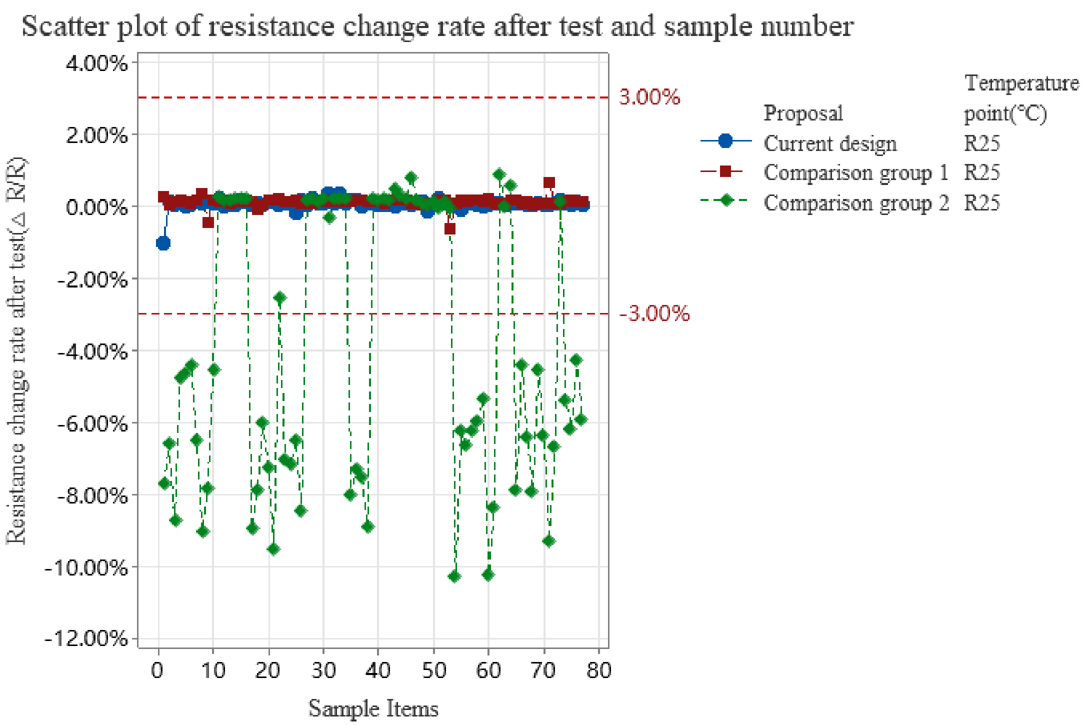
(a) R25 data before and after the current design test



(b) Comparison of R25 data before and after the test in group 1



(c) Comparison of R25 data before and after the test in group 2



(d) Data graph of resistance change rate after the experiment for the current design, comparison group 1 and comparison group 2

Figure 6. Diagram of NTC sensor test result analysis

5. Conclusion

The method proposed in this paper uses double-layer Teflon (inner tube FEP, outer tube PTFE) heat shrink tubing to heat shrink the NTC thermistor. The advantages are simple manufacturing process, low cost and excellent waterproof performance, which can replace epoxy resin coating. The following conclusions can be drawn from the experimental research results: (1) The temperature sensor made of double-layer Teflon heat shrink tubing to heat shrink the NTC thermistor has excellent waterproof performance and can greatly improve the service life of the temperature sensor. (2) The design of heat shrinking the NTC thermistor using double-layer Teflon heat shrink tubing can be fixed with different shell types and can be widely used in scenarios with high waterproof requirements.

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