

Study on the Measuring and Reading Mode of High Precision Thermometer in Hydraulic Engineering

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Abstract. After the operation of large water conservancy projects, water temperature changes will have a significant impact on the surrounding ecological environment. In order to monitor the water temperature, a water temperature monitoring system covering the whole flow channel has been established in China's giant hydropower stations. In order to accurately measure the water temperature in the water level fluctuation area, a ± 0.1 °C water temperature gauge is selected as the front sensing device. Compared with traditional thermometers, high-precision thermometers are rarely used in projects. After investigation and comparison, platinum resistance thermometer has been applied in water conservancy projects. In view of the fact that there is no special manual measuring and reading equipment for the platinum resistance thermometer before the automation is connected during the construction period, a four wire temperature measuring and reading mode is proposed, which is applicable to the platinum resistance thermometer by using the existing hydraulic bridge, and the rationality of the measuring and reading mode is verified through the comparison of indoor tests.

Keywords. Water conservancy projec, temperature monitoring, high precision thermometer, manual reading.

1. Introduction

In the context of the current great protection of the Yangtze River basin [1], in order to mitigate the adverse water temperature impact caused by the construction of the Project, the hydropower stations in the Yangtze River basin are equipped with water temperature monitoring systems in the reservoir area, in front of the dam and at the downstream of the dam. During the operation period, the water temperature in the river reach is comprehensively and systematically monitored. The online monitoring system of water temperature includes the online monitoring system of water temperature along the reservoir area, the online monitoring system of vertical water temperature at the water intake, the online monitoring system of water temperature in the unit channel and the online monitoring system of water temperature under the dam. According to the prediction results of the water temperature prediction model in the reservoir area of the power station and the vertical stratification characteristics of the water temperature, the water pressure resistance and accuracy of the thermometer are reasonably selected. The water temperature gauge with an accuracy of ± 0.3 °C is proposed to be selected in the area with relatively stable water flow and temperature below the elevation of 700m, and the water temperature gauge with an accuracy of \pm

0.1 °C is proposed to be selected in the area with major changes in the water level above the elevation of 700m. At present, the temperature sensors commonly used in the safety monitoring of water conservancy projects are mostly resistance thermometers and vibrating wire thermometers, which meet the accuracy of ± 0.3 °C. Compared with the traditional thermometer, the water temperature gauge with ± 0.1 °C accuracy is less used in the safety monitoring of water conservancy projects. This paper defines it as a high-precision thermometer, and explores the selection of high-precision thermometer in the water temperature monitoring system of Baihetan Hydropower Station, the measurement and reading mode during construction and the application effect.

2. Thermometer selection

2.1 Introduction to Common Thermometers

Temperature sensors are embedded in or on hydraulic structures or other geotechnical structures for a long time to measure the temperature inside the concrete of hydraulic structures, water temperature in the reservoir area, ambient air temperature, etc. The temperature sensors commonly used in water conservancy projects are mostly resistance thermometers. The Inspection and Test Procedures for Dam Safety Monitoring Instruments (SL530-2012) also stipulates the inspection and test

methods and procedures for three types of thermometers, namely copper resistance thermometer, thermistor thermometer and vibrating wire thermometer. Copper resistance thermometer is a thermometer that uses copper resistance to work in a linear relationship with temperature within a certain temperature range. The thermistor thermometer uses the semiconductor thermistor as the sensor. With the characteristics that the number of carriers in the semiconductor increases drastically with temperature, the more carriers, the stronger the conductivity, and the smaller the resistivity, the temperature is measured by measuring its resistance value. It is just opposite to the temperature change characteristic of copper resistance thermometer. When the ambient temperature changes, the vibrating wire thermometer transmits to the internal inductor through the sensor. Because the temperature has a linear relationship with the change of the inductor, the inductor expands or contracts, causing the natural frequency of the vibrating wire to change. The current ambient temperature change can be calculated by the secondary instrument exciting the vibrating wire through the coil and receiving the digital signal.

These three types of thermometers have been used in water conservancy projects for a long time with good results, and portable and mature secondary instruments are used together during the construction period. Table 1 lists the relevant indicators of typical thermometers.

Table 1 Comparison Table of Typical Thermometer Parameters

Type	Copper resistance	Thermistor	Vibrating wire
Measuring range	-30°C~70°C	-25°C~80°C	-20°C~80°C
Measurement accuracy	±0.3°C	±0.5°C	≤0.03°C/F
Resolution	/	0.1°C	≤0.03%F.S
Measurement and reading method	Hydraulic bridge	Vibrating wire reader with temperature measurement	Vibrating wire reader

2.2 Selection of high-precision thermometer

Through the manufacturer's investigation and comparison of different types of thermometers, platinum is an ideal thermometer material, which is easy to be purified, processed, and has good physical and chemical stability. The thermometer with platinum resistance as the sensor has excellent temperature measurement performance, such as wide temperature measurement range, stable performance, and good repeatability, and can meet the ±0.1 °C accuracy requirements of the project. From the perspective of application, standard platinum resistance thermometers are often used as verification instruments for various standard thermometers and precision temperature measuring instruments, and are widely used in high-precision temperature control systems in high-tech, industrial production and scientific research fields.

The platinum resistance thermometer used in this project has the characteristics of good long-term stability, stainless steel structure suitable for various harsh environments, good waterproof performance, long service life, high sensitivity, etc. See Table 2 for technical parameters.

Table 2 Instrument Technical Parameters

Type	Parameters
Measuring range	-30°C~+70°C
Measurement accuracy	±0.1°C
Sensitivity	0.1°C
Stability	≤0.1%/Y
Withstand voltage	1500V
Insulation resistance	≥100MΩ
Resistance	100Ω@0°C

3. Study on the measurement and reading mode during construction

3.1 Measurement and reading method

In water conservancy projects, the connecting cable of monitoring instruments is usually long, up to thousands. The platinum resistance thermometer has small resistance and high sensitivity. For example, the thermal resistance of the platinum resistance is 0.379 Ω/°C at 100 °C. If the resistance of the connecting cable is 2 Ω, the error will reach 5.3 °C. Therefore, when measuring and reading the resistance of the sensor normally, the measurement error caused by the resistance of the cable led by the instrument must be eliminated [2].

As mentioned in the above section, platinum resistance thermometers are commonly used in precision industrial systems. The user manual of the selected thermometer gives the access and reading methods of the automatic acquisition system. There is no method for accurate measurement and reading without access to automation during the construction period, and there is no matching portable measurement and reading instrument. From the perspective of instrument principle, it is obvious that high-precision thermometers cannot use vibrating wire readout or the accompanying temperature module of vibrating wire readout to measure and read. Therefore, starting from the platinum resistance measurement principle in the industrial field, the feasibility of using the mature copper resistance thermometer that is also used to measure resistance for reference is analyzed.

There are three international measurement methods for thermal resistance leads [3], namely two-wire system, three wire system and four wire system. Two wire system is a way to connect a wire at both ends of the thermal resistance to lead out the resistance signal. This lead wire method is very simple, but because there must be lead wire resistance r in the connecting wire, the size of r is related to the material and length of the wire, so this lead wire method is only applicable to the occasions with low measurement accuracy. The three wire system is a way to connect one lead at one end of the root of the thermal

resistance and two leads at the other end. This method is usually used with the bridge, which can better eliminate the influence of lead resistance. It is the most commonly used method in industrial process control. The four wire system is a way to connect two conductors at the root and both ends of the thermal resistor. Two leads provide the thermal resistor with constant current I , convert R into voltage signal U , and then lead U to the secondary instrument through the other two leads. It can be seen that this lead way can completely eliminate the influence of lead resistance, and is mainly used for high-precision temperature detection.

The thermometer selected is a four core cable, so it is proposed to use the four wire system method of double arm bridge for measurement and reading. There are mature bridge products in the field of safety monitoring of water conservancy projects, which are mainly used for the measurement of resistance ratio, resistance value, reverse resistance ratio and core wire resistance of differential resistance instruments, and can eliminate the influence of long cable resistance and core wire resistance variation on the measured value. The differential resistance instrument uses a five core hydraulic cable, and the existing bridge products are designed according to this. The measured resistance value can be obtained by matching the color of the five terminal posts of the bridge with the five core hydraulic cable core. Starting from the measuring principle and the principle of instrument and equipment, the four wire method is used to measure the platinum resistance thermometer with the existing bridge products.

The wiring equivalent diagram of four wire temperature measurement is shown in Figure 1, where R_t is the thermal resistance and R_{L_i} is the equivalent resistance of conductor L_i . Apply exciting current I to the thermal resistance through wires L_1 and L_2 , measure the potential V_3 and V_4 , connect wires L_3 and L_4 to the high input impedance circuit, and make $I_{L_3}=0$ and $I_{L_4}=0$. Therefore, V_4-V_3 is equal to the voltage at both ends of the thermal resistance, and then use formula (1) to obtain the thermal resistance value [4].

$$\frac{(V_4 - V_3)}{I} = R_t \quad (1)$$

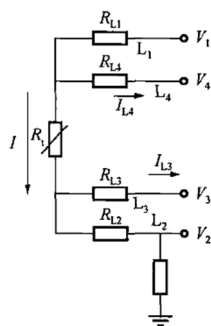


Fig. 1 Equivalent schematic diagram of four wire system temperature measurement

By analyzing the internal structure of the existing bridge products, the connection mode of the four core measuring and reading cable of high-precision thermometer using

the four wire system method is shown in Figure 3. The measured temperature can be calculated using the temperature resistance characteristics of the platinum resistance, and the calculation formula is Formula (2).

$$R_t = R_0 \left[1 + aT - bT^2 - cT^3 (T - 100) \right] \quad (2)$$

Where, R_t is the resistance value when the temperature is T , R_0 is the resistance value thermal resistance when the temperature is 0°C , and a, b, c are coefficients. Platinum resistance is used for the instrument as $\text{TCR}=0.003851$ in accordance with IEC751 standard. See Table 3 for coefficient values.

Table 3 Coefficient value table when $\text{TCR}=0.003851$

Temperature	a	b	c
$T < 0^\circ\text{C}$	3.90802×10^{-3}	5.80195×10^{-7}	4.27351×10^{-12}
$T \geq 0^\circ\text{C}$	3.90802×10^{-3}	5.80195×10^{-7}	0

At present, there is little practice of measuring and reading high-precision (platinum resistance) thermometers by hydraulic bridges in literature and work. The validity of the wiring mode of measuring and reading high-precision (platinum resistance) thermometers by hydraulic bridges will be tested and verified below.

3.2 Test verification

3.2.1 Instrument and equipment

The equipment used in the test includes thermostatic water tank (the maximum temperature difference in the working area shall not exceed $\pm 0.1^\circ\text{C}$), second-class standard mercury thermometer, electric bridge, multimeter and other secondary instruments. The thermostatic water tank is used to provide a standard temperature environment for the instrument. The platinum resistance thermometer and mercury thermometer are all immersed in the thermostatic water tank. The mercury thermometer is used to correct the temperature environment. The instrument is measured by an electric bridge and a multimeter. The two secondary instruments represent the four wire system and the two wire system respectively. The measured results are used for comparison.

3.2.2 Test result

The test was carried out in a standard laboratory in strict accordance with the Inspection and Test Procedures for Dam Safety Monitoring Instruments (SL530-2012). At 0°C , 30°C and 60°C three temperature points in the thermostatic water tank, the thermometer is connected to 3m cable, 50m cable and 100m cable, and the resistance is measured with an electric bridge and multimeter respectively, and then the temperature value is calculated. See Table 4 for the test results.

Table 4 Temperature measurement

Standard temperature (°C)		0	30	60
With 3m long cable	Bridge measurement (°C)	-0.03	29.96	59.96
	universal meter measurement (°C)	0.84	30.84	60.84
With 50m long cable	Bridge measurement (°C)	0.04	30.02	60.04
	universal meter measurement (°C)	5.37	35.39	65.46
With 100m long cable	Bridge measurement (°C)	-0.01	30.02	60.04
	universal meter measurement (°C)	10.76	40.88	71.00

The results show that:

(1) The multimeter is directly used to measure with the two-wire wiring method. With the increase of the instrument wiring length, the error of the measurement results will increase accordingly, because the two-wire system cannot eliminate the cable error.

(2) The bridge measurement is conducted by using the four wire wiring method. The error at each test temperature point is small. Under the laboratory conditions, the maximum error is ± 0.04 °C, which is not affected by the instrument wiring length. This shows that the precision of the platinum resistance thermometer selected meets the engineering needs, the measuring instrument selected is appropriate, and the four wire system wiring mode studied is correct.

4. Conclusion

Research methods such as extensive investigation and indoor test are adopted to explore the selection of high-precision thermometers in the water temperature monitoring system of large hydropower stations and the measurement and reading methods during construction. The main conclusions are as follows:

(1) Platinum resistance thermometer has good performance, its accuracy is superior to the commonly used hydraulic monitoring thermometer, its accuracy meets the requirements of engineering design, and the instrument selection is accurate.

(2) Through the indoor comparison test, the platinum resistance thermometer can be manually measured and read by the existing hydraulic bridge according to the four wire system described in the article. The measurement and reading results are far better than the two wire system, which can eliminate the error caused by connecting cables.

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References

1. Q.X. Fan. Water resources utilization based on sustainable ecosystems. Practice of Jingsha river hydropower development, Journal of Hydroelectric Engineering, vol. 29 (2010) No.4, p.1-5+13.
2. Y. Zhang. Accurate measurement of industrial thermal resistance, Metrology & Measurement Technique, (2004) No. 4, p.6-7.
3. M. Zhou, X.S. Ge. Research on measuring method of three wire and four wire thermal resistance, Industrial Metrology, vol. 25 (2015) No.3, p.33-37.
4. X.W. Zhang, K. Zhang. Application of high precision digital multimeter in platinum thermistor temperature measurement, China Metrology, (2005) No. 10, p.71-72.