Two-Wire Resistance Temperature Detectors

Subjects: Engineering, Electrical & Electronic
Contributor: Li Wei

In the remote measurement system, the lead wire resistance of the resistance sensor will produce a large measurement error. In order to ensure the accuracy of remote measurement, a novel lead-wire-resistance compensation technique is proposed, which is suitable for two-wire resistance temperature detector. By connecting a zener diode in parallel with the RTD and an interface circuit specially designed for it, the lead-wire-resistance value can be accurately measured by virtue of the constant voltage characteristic of the zener diode when reverse breakdown, compensation can thereby be made when calculating the resistance of RTD. Through simulation verification and practical circuit test, when the sensor resistance is in 848 - 2120 Ω scope and the lead wire resistance is less than 50 Ω, the proposed technology can ensure the measuring error of the sensor resistance within ± 1 Ω and the temperature measurement error within ± 0.3 ℃ for RTDs performing 1000 Ω at 0 ℃. Therefore, this method is able to accurately compensate the resistance of two-wire RTD lead and is suitable for most applications.

Keywords: RTD ; zener diode ; temperature measurement ; lead wire

1. Introduction

High-precision temperature measurement provides basic data for product development and industrial automation applications to improve product quality and ensure production safety. Due to its excellent linearity, measurement repeatability and stability[1], a resistance temperature detector (RTD) is widely used therein. However, for remote measurements, the electrical resistances of long connecting lead wires between the RTD and the control room instrument produce an appreciable error in measurement. This unwanted error varies not only with the length of the lead wires but also with ambient temperature variations where the lead wires layout [2]. Therefore, methods to reduce or eliminate measurement errors caused by lead wire resistance have been studied in many literatures.

2. Currant status

Currently, the aforementioned problem is addressed by adding lead wires. For example, in Reference[3] [4]three-wire and four-wire techniques were used separately. However, the cost of one additional lead wire in a three-wire RTD and of two additional lead wires in a four-wire RTD will be extremely high and with extra difficulty of wiring, especially in industries where a large number of process points are to be monitored from a control room located at a remote place [5], such as chemical, thermal power, electric plant and other industries. In the bridge-based measuring system, lead wire resistance also exerts an adverse effect on measurements. Authors in Reference[6][7] presented a method to eliminate lead wire resistance for quarter- and half-bridge interface circuit respectively, which employed several operational amplifiers (OPAMPs) and made use of their high input impedance. This method was able to eliminate the unfavorable effect on the measurement caused by lead wires, but it cannot obtain the specific lead-wire-resistance values, in addition, its interface circuits and power circuits were complicated due to the OPAMPs. Similar methods using OPAMPs were also published in Reference [8][9][10]. All of these bridge-based interface circuits used a three- or four-wire method, except for Reference[6].

Therefore, researches have been carried out on the compensation method of two-wire sensors. In Reference [11], a compensation resistor is selected having the same value and of the same material of the lead resistances combined with three operational amplifiers and a constant current source to compensate the lead wires error. Although the circuit of this method is simple, the compensation resistance must be adjusted manually if the lead wire length is changed due to reconstruction. In addition, the compensation effect due to temperature drift of the lead wire resistance remains to be validated. The authors [5] of proposed a novel lead-wire-resistance compensation technique using a two-wire RTD. This technique employed two diodes, one of which was in series with the RTD and the other was in parallel with the series circuit composed of the RTD and the first diode. A current source, four analogy switches and four sample-holding circuit were used in its interface circuit, and an operational amplifier is used to output the voltage with respect to the RTD resistance. In principle, this technique completely eliminated the measurement error caused by the lead wire resistance and its temperature drift, but its measurement accuracy depended on the consistency of the forward voltage drop of the two diodes. Therefore, in order to achieve a high precision measurement, it is indispensable to measure and pair the diodes in advance. Besides, this technique cannot obtain the true value of the lead wire resistance. This method was also seen in other references, and some improvements had been made in the interface circuit. In the Reference [12], three single-pole double-throw (SPDT) analog switches are used to realize the lead-wire-resistance compensation, which was independent of the voltage reference. The authors of [13][14]used a voltage-to-current converter to provide the current and reduced the number of SPDT analog switches to two. A Chinese patent invented a method that employed the transient characteristics of resistor–capacitor (RC) circuit to measure the lead wire resistance and compensate measurement error of the thermal resistance. In this method, the measurement precision is not affected by the characteristics of the additional capacitor, and the lead-wire-resistance value could be obtained in real time, which avoided the negative influence of the temperature drift of the lead wire resistance. According to the patent, the update rate is less than 5 Hz, and it is not suitable for the applications where temperature changes need to be tested dynamically. In References [15][16], the interface circuits for four-wire resistive sensor were designed by the similar method of multiple charge and discharge to a capacitor, and the update rate reported was 25 Hz. The authors in References [17][18] combined the method for two-wire sensors reported in Reference [5] and also proposed the method using a capacitor, and the their minimum complete measurement cycle required 5.3 ms. These methods have the same problem of limited update rate.

References

1. Maxim, RTD Measurement System Design Essentials. Available online: https://www.maximintegrated. com/cn/design/technical-documents/app-notes/6/6262.html (accessed on 15 February 2020).
2. Maiti, T.K.; Kar, A. Novel Remote Measurement Technique Using Resistive Sensor as Grounded Load in an Opamp Based V-to-I Converter. IEEE Sens. J. 2009, 9, 244-245.
3. Tipparat J. Interface Circuit for Three-Wire Resistance Temperature Detector with Lead Wire Resistance Compensation. Proceedings of 2019 Research, Invention, and Innovation Congress (RI2C), Bangkok, Thailand, 11-13, December, 2019; IEEE: New York, USA, 2020.
4. Erkan, K.; Akkoyunlu, B.; Balkan, E.; Tayanc, M. A portable borehole temperature logging system using the four-wire resistance method. J. Geophys. Eng. 2017, 14, 1413-1419.
5. Maiti, T.K. A novel lead-wire-resistance compensation technique using two-wire resistance temperature detector. IEEE Sens. J. 2006, 6, 1454-1458.
6. Vishal J.; Boby G. An efficient digitization scheme for resistive sensors interfaced through quarter bridge. Proceedings of 2017 Eleventh International Conference on Sensing Technology (ICST), Sydney, NSW, Australia, 4-6 December 2017; IEEE: New York, USA, 2018.
7. Vishal J.; Boby G. Self-balancing digitizer for resistive half-bridge. Proceedings of 2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Houston, TX, USA, 14-17 May 2018; IEEE: New York, USA, 2018.
8. Pradhan, S.; Sen, S. An Improved Lead Compensation Technique for Three-Wire Resistance Temperature Detectors. IEEE Trans. Instrum. Meas. 1999, 48, 903-905.
9. Lai, L.; Feng, J.; Shi, L.B. Quasi-Balance Four-Terminal Resistance Bridge. IEEE Trans. Instrum. Meas. 2015, 64, 1636-1641.
10. Kishore, K.; Malik, S.; Baghini, M.S.; Akbar, S.A. A Dual-Differential Subtractor-Based Auto-Nulling Signal Conditioning Circuit for Wide-Range Resistive Sensors. IEEE Sens. J. 2020, 20, 3047-3056.
11. Sen, S.K. An improved lead wire compensation technique for conventional two wire resistance temperature detectors (RTDs). Measurement 2006, 39, 477-480.
12. Elangovan, K.; Anoop, C.S. Simple and Efficient Relaxation-Oscillator Based Digital Techniques for Resistive Sensors - Design and Performance Evaluation. IEEE Trans. Instrum. Meas. in press.
13. Petchmaneelumka, W.; Julsereewong, P.; Julsereewong, A.; Tongpakpanang, J. Simple Interface Circuit with Lead-Wire-Resistance Compensation for Single Resistive Sensors. Proceedings of 12th International Conference on Control, Automation and Systems (ICCAS), ICC, Jeju, South Korea, 17-21, October, 2012; IEEE: New York, USA, 2012; pp. 1076-1079.
14. Prasit J.; Amphawan J.; Apinai R.; Nakorn P. Simple resistance-to-time converter with lead-wire-resistance compensation. Proceedings of SICE Annual Conference 2011, Tokyo, Japan, 13-18, September, 2011; IEEE: New York, USA, 2011.

15. Philip, V.N. Direct Microcontroller Interface based Digital Readout Circuit for Single-Element Resistive Sensors. Proceedings of IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (IEEE ICPCSI), Chennai, India, 21-22, September, 2017; IEEE: New York, USA, 2018; pp. 2480-2483.
16. Philip, V.N. Digital readout circuit with direct microcontroller interface for bridge-connected resistive sensors. Proceedings of 2017 IEEE International Conference on Circuits and Systems (ICCS), Thiruvananthapuram, India, 20-21, December, 2017; IEEE: New York, USA, 2018.
17. Ramya A.; Umapathy M.; Uma G. Enhanced Microcontroller Interface of Resistive Sensors through Resistance-to-Time Converter. IEEE Trans. Instrum. Meas. in press.
18. Nagarajan, P.R.; George, B.; Kumar, V.J. Improved Single-Element Resistive Sensor-to-Microcontroller Interface. IEEE Trans. Instrum. 2017, 66, 2736-2744.