Measurement and application of high-value resistance

Yazhen Tong
Product department
Beijing Orient Institute of Measurement and Test
Beijing, China
tongyazhen016@163.com

Shangming Sang
Product department
Beijing Orient Institute of Measurement and Test
Beijing, China
sangshm@163.com

Ming Yan
Product department
Beijing Orient Institute of Measurement and Test
Beijing, China
1124774523@qq.com

Xian Zhang
Product department
Beijing Orient Institute of Measurement and Test
Beijing, China
zhangxian@163.com

Xingxi Wen
Product department
Beijing Orient Institute of Measurement and Test
Beijing, China
18701066383@163.com

2021 IEEE 15th International Conference on Electronic Measurement & Instruments (ICEMI) | 978-1-6654-4491-0/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICEMI52946.2021.9679510

***Abstract*—High-value resistance generally refers to the DC resistor with a resistance value of more than 1M or 10M which is widely used in electrometer, microammeter, insulation tester and other instruments, among which its stability is the key factor to determine the performance of instruments. Therefore, it is necessary to measure the temperature and voltage characteristics of high value resistance. The traditional bridge method can only measure high value resistance at low voltage. The paper demonstrates a measurement method for high value resistance, which is realized by a set of measurement device composed of multi-functional standard source and electrometer. It can meet both low voltage and high voltage conditions. This method is compared with the bridge method to measure the same high value resistance. It is concluded that the measurement method proposed in this paper is closer to the actual situation of high value resistance. At the same time, the paper analyzed effects of insulating materials, external electromagnetic interference, bending or vibration of the measurement cable, pollutants in the test environment on high resistance measurement, and puts forward some preventive measures to improve the accuracy of measurement It is suitable for the measurement of high-value resistance in general laboratories, and has practical application value.**

Keywords—High-value resistance, Measurement, Error

I. INTRODUCTION

High-value resistance generally refers to the DC resistor with a resistance value of more than 1M or 10M. Its components are widely used in high-resistance meter, electrometer, insulation tester, microammeter and other instruments, so as to complete various specific functions. Compared with medium and low resistance, the measurement and standard of high-resistance start relatively later. Along with the development of various semiconductor materials, insulating materials and photoelectric devices, instrument manufacturers have launched high resistance meter, electrometer, microammeter to measure high-value resistance and micro current[1-4]. As the standard of internal instrument and instrument calibration, high-value resistance has been paid more and more attention.

The measurement of high-value resistance can generally be realized by ohm's law, that is, $R=V/I$, divided into two methods, namely constant voltage method and constant current method where the former is to make the known DC current flow through the measured value of resistance, and calculate the value of the high-value resistance by measuring the voltage at both ends of the high-value resistance, while the latter is to apply the known DC current to both ends of the resistance to be measured and calculate the value of the high-value resistance by measuring the current of the high-value resistance[5-8]. Whereas since the measured voltage has GΩ level source impedance, constant current method generally reduces the accuracy of measurement significantly. Therefore, the constant voltage method is generally applied to measure high-value resistance. At present, the bridge method is mainly used for the accurate measurement of high-value resistance in China, which is of high accuracy, while can only measure the high-value resistance at low voltage[9]. Moreover, the equipment is imported equipment, with relatively high price. Once any problems on equipment, it will takes high maintenance cost, and long time, not applicable to the general laboratory of high-value resistance measurement. Based on the existing instruments in the laboratory, this paper carried out relevant research work, and built a set of high-value resistance measurement device by means of multi-functional standard source and electrometer, which can not only realize the measurement of high-value resistance at low voltage and high voltage[10]. This method is compared with the bridge method to measure the same high-value resistance. It is concluded that the measurement method proposed in this paper is closer to the actual situation of high-value resistance, effectively solve the practical problem of high-value resistance measurement.

II. MEASUREMENT METHOD OF HIGH RESISTANCE

As an measurement instrument of weak current signal such as electrometer and microammeter and the internal standard component of small current standard source, the influence of resistance error can be eliminated by calibration. The stability of high-value resistance determines the performance of instrument and meters. Thus, it is necessary to pay more attention to the voltage and temperature characteristics of high-value resistance[11].

The resistance value of high-value resistance is usually the nonlinear function of its borne voltage. Since the electric conductor of the resistance is formed by the dispersion conductor, and there is the internal contact resistance, there is nonlinear relationship, namely the current flowing through high resistance is not strictly proportional to the voltage[12]. Whereas the resistance rises and falls by the voltage, the

978-1-6654-4491-0/21/$31.00 ©2021 IEEE

voltage coefficient can be used to describe the relationship between the resistance value and voltage, which is measured by constant voltage method. The measuring principle diagram is shown in the figure below, that is, placing the high-value resistance to be measured at constant temperature and humidity box, maintaining a constant temperature and humidity, providing different DC voltage values by means of multi-function standard source 5720A, and then measuring the current flowing through high-value resistance by the current measurement function of the electrometer 6517B, thus calculating the voltage coefficient of the high-value resistance.

The 5720A can provide a wide range of DC voltages from as low as 10mV to as high as 1100V with accuracy up to 4E-6 ~ 8E-6 and can measure high-value resistance at both low and high voltages. The current measurement accuracy of 6517B is 0.2%, where the current measurement function and index of 6517B are calibrated by standard resistor and high-precision calibration source, so that its stability and accuracy can be ensured.

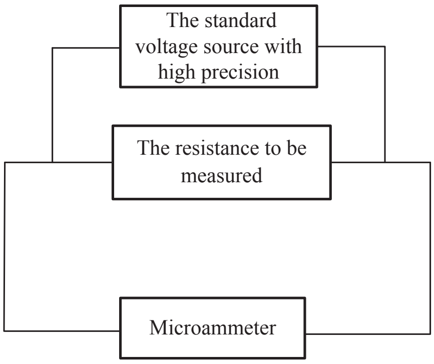

Fig. 1. Measurement principle diagram of voltage coefficient of high value resistance

The resistance value of high-value resistance varies by the temperature, and is related to the conductive material, substrate, insulating paint, structure and manufacturing method of the resistor. In order to evaluate the temperature characteristics of resistance, it is usually expressed by temperature coefficient, and within a certain temperature range, its temperature characteristics are usually linear, among which the temperature coefficient measurement is to place the high-value resistance into the high and low temperature box, and use the measuring method of voltage coefficient to measure the high-value resistance at different temperatures respectively. After calculation, the temperature coefficient of the high-value resistance can be obtained.

TABLE I. THE SPECIFICATIONS OF KEITHLEY 5156 HIGH-VALUE RESISTANCE

Nominal value	Temperature coefficient	Voltage coefficient
1GΩ	<25ppm/℃	<1ppm/V

After relatively measuring the KEITHLEY 5156 high-value resistance (nominal value 1GΩ) by means of the bridge method and this method, the technical specifications are shown in the following table, which shows that the high value resistance has low temperature coefficient and voltage coefficient. Among that, during the test, the high end of the resistance is a triaxial connector, and the low end of the resistance is a coaxial connector, which is conducive to form a shielding envelope and reduce the external electromagnetic interference.

III. ERROR ANALYSIS OF HIGH-VALUE RESISTANCE MEASUREMENT

High-value resistance is affected by many factors in the process of measurement, as so to affect the measurement results, where the quality of material insulation, measurement methods, shielding methods, protection measures, test cables, etc., will have a great impact on the measurement results.

Insulating materials have a great impact on the measurement accuracy of high-value resistance. Good insulating materials can reduce the interference during measurement. When the insulation resistance of an insulator approaches the air gap resistance, its parasitic current will become very small. The current can cause surface leakage through the insulating material or the insulating part of connecting the conductor and the insulating material itself may store and generate electric charge[13], so it is necessary to choose a good insulating material. In the high-value resistance measurement, when using the cable to connect high-value resistance to be measured and meter, double-layer polyethylene can be used to shield coaxial cable, that is, the inner core wire is connected to the high end of input signal, intermediate shielding layer is connected to the low end of output signal, and outer shielding layer is connected to the shell. In this way[14], its parasitic current will be very small under the mechanical action, and it's relatively fixed. In addition, it is necessary to keep the surface clean and by means of shielding technology, ensure that the leakage resistance of distributed capacitance and cable has a minimum impact on the measurement shielding technology, so as to make the measurement data more accurate and stable.

In the process of high-value resistance measurement, the external electromagnetic interference will cause induction phenomenon, which seriously affects the measurement results, so it is necessary to adopt shielding technology to solve the electromagnetic interference[15]. When measuring, the resistance to be measured should be placed in a fully closed shielding box, the surface of the shielding box should have an interface consistent with the low-noise cable used for measurement, and at the same time, the measurement signal should be completely insulated from the shielding box. In addition, the measurement signal should be completely wrapped in the shielded box, avoiding suffering from electromagnetic interference in the air due to direct exposure. Moreover, the shielding box should be effectively connected to the ground. In this way, any interference current caused by external electromagnetic or electrostatic field will be introduced to the ground, ensuring that the shielding box is always in a state of zero potential, so as to provide a good guarantee for accurate measurement. The grounding of the shielding box should avoid the formation of a ground loop. When the shielding box is effectively grounded at a single point, its common-mode voltage will not affect the measurement because there is no current between the conductive layers. While if conductive layers are connected at multiple points, current loops will be formed, resulting in that common-mode voltages seriously affect measurements of high value resistance.

If there is any friction between the insulator and conductor in the cable by bending or vibration of measuring cable, the noise current will be generated. Although the use of low-noise cable can effectively reduce this effect, when subjected to bending or vibration, a certain amount of noise will still be generated. Therefore, the connection between measuring cable should be as short as possible, and attention should be paid to avoid vibration association between different parts of the test system, so as to improve the accuracy of measurement data.

In a high humidity environment, pollutants will occur electrochemical reaction, resulting in a certain amount of interference current. So in the measurement of high-value resistance, it is necessary to choose the insulation material that can not absorb water, and ensure the humidity of the test environment at a relatively dry situation, so as to increase the accuracy of measurement.

Leakage current caused by the parasitic resistance path between the measurement circuit and the nearby voltage source is generally generated during high-value resistance measurement, which will seriously affect the measurement results. Thus, in addition to the use of high-quality insulation materials and the reduction of humidity in the test environment, appropriate grounding and other protection measures should be used to reduce leakage current.

IV. Measurement Results and Analysis

In terms of Keithley 5156 high-value resistor (nominal value 1GΩ), when adopting the bridge method only under low voltage conditions. The measurement results of voltage coefficient and temperature coefficient are shown in Figure 2. Figure 2 (a) is the measurement result of voltage coefficient measured by the bridge method, the abscissa is the voltage applied at both ends of high-value resistance, the unit is V, the voltage range is 0-25V, and the ordinate is the voltage coefficient, the unit is 1/V. Figure 2 (b) shows the measurement results of the temperature coefficient measured by the bridge method. The abscissa is the temperature, the unit is ℃, and the ordinate is the temperature coefficient, the unit is 1 / ℃.

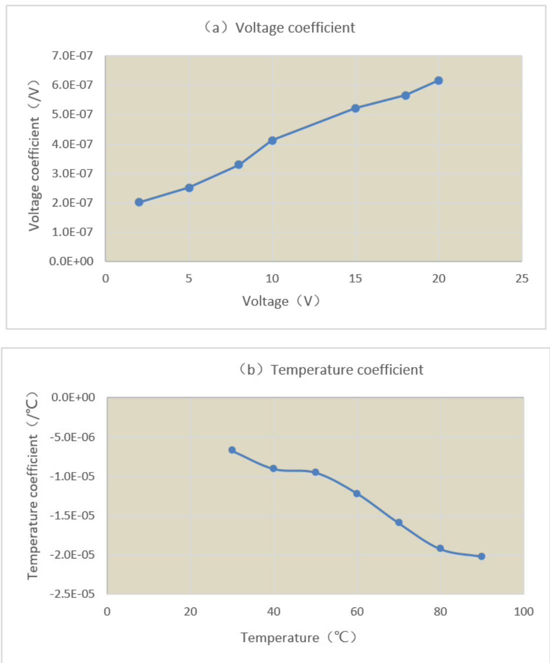

Fig. 2. Measurement result of 1GΩ 5156 high-value resistance using the bridge method

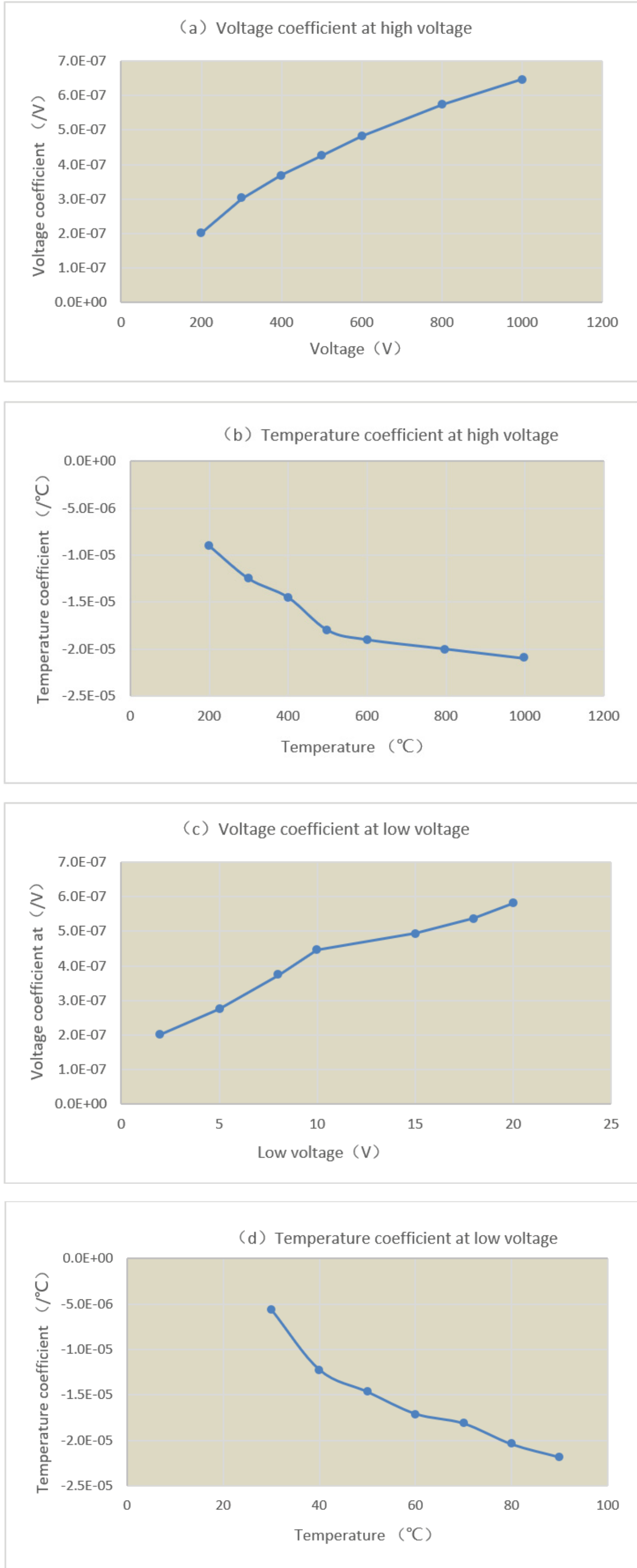

Fig. 3. Measurement result of 1GΩ 5156 high-value resistance using the constant voltage method

In terms of Keithley 5156 high-value resistor (nominal value 1GΩ), when adopting the high-value resistance measurement device built by multifunctional standard source and electrometer under both high voltage and low voltage conditions. The measurement results of voltage coefficient and temperature coefficient are shown in Figure 3. Figure 3 (a) is the result of voltage coefficient measured by this method under high voltage. Figure 3 (b) is the result of the temperature coefficient measured by the method under high voltage, Figure 3 (c) is the result of the voltage coefficient measured by the method under low voltage, and figure 3 (d) is the result of the temperature coefficient measured by the method under low voltage.

In this paper, the bridge method can only be used to measure high-value resistance under the condition of low voltage, while the measuring methods of high-value resistance can be used under the condition of both high voltage and low voltage. According to the measured results of above, it can be seen that the high voltage coefficient and temperature coefficient of 5156 high-value resistance value measured by both the bridge method and voltmeter-ammeter method are conform to the technical indicators, and measurement results are higher than technical indicators, thus the experiment shows that the measurement method of high-value resistance is accurate and has practical significance. The temperature coefficient of the high-value resistance is negative, and its order of magnitude is 1E-5. The temperature change at 1000V is 10℃, and at that time the order of magnitude of relative change of resistance caused by the temperature coefficient is 1E-4. The voltage coefficient is positive and the order of magnitude is 1E-7 and when the voltage changes 1000V, the order of magnitude of relative change of resistance caused by the voltage coefficient is 1E-4. Furthermore, when the high-value resistance works at 1000V, the relative change of the resistance value caused by the voltage coefficient and the temperature coefficient is on the same order of magnitude, while only the symbol is opposite, which is beneficial to improve the stability of the resistance.

V. Application Scenarios of High-Value Resistance

High-value resistance with thin film or carbon film has the characteristics of high resistance, large voltage coefficient and good stability, is often used as sampling resistance in micro-current measurement instrument, and is generally measured in low voltage measurement, so that the voltage drop of micro current to be measured is formed on the high-value resistance (that is, I/V conversion), and then the value of micro current to be measured can be indirectly obtained by measurement of the output voltage. The following figure shows the basic circuit that sampling method of the high resistance measures the micro current, among which, R is the high-value resistance used for sampling. As long as its accurate value is known and the output voltage is measured with a high-precision voltmeter, then the value of the micro current can be measured indirectly as $I_{IN}=V_{OUT}/R$.

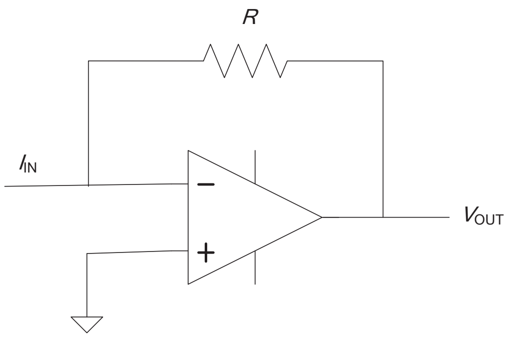

Fig. 4. Application of high-value resistance in IV circuit

High-voltage and high-value resistance is mainly used in electrometer, high voltage meter and other kinds of insulation measuring instruments, for voltage division or discharge, and requiring the measurement is conducted under the nominal high voltage.

VI. Conclusion

This paper introduces the measurement method of temperature characteristic and voltage characteristic of high-value resistance, analyzes the impact of insulation materials, electromagnetic interference, bending or vibration of cable, and pollutants on measurement error of high-value resistance, puts forward some prevention measures to improve the measurement accuracy of the high-value resistance, as well as describes different application scenarios of high-value resistance at the conditions of both low voltage and high voltage.

References

[1] Xu jianyuan, Ge Xiaohui. “Application and research on non-balanced bridge”. Journal of Qingdao university, vol. 14, pp. 74-76, 2001.

[2] Cao Guiqin, Wang Dewen. “Measurement Technology of High-Value Resistance “. Enterprise Standardization, vol. 6, pp. 35-37, 2005.

[3] Jia Guihua, Zhang Ping, Deng Guorong. “DC Weak Current Measurement and Error Analysis”. Information and Electronics Engineering, vol. 6, pp. 609-612, July,2009.

[4] Zhang huizhi, Wu zhancheng. “Analysis and Research on High-Value Resistance Measurement”. Journal of Ordnance Engineering College, vol.18, pp. 45-48, September,2006.

[5] Wang Rendao, Wang Yuzhen, Zhai Xicai. “Application of High-value Resistance in Weak Current Measurement”. vol.6, pp. 34-37, April,1987.

[6] Li dengyun, Liu gaojia. “Measurement For Temperature Coefficient And Voltage Coefficient of High-precision Resistance at High Voltage Condition”. Electric Measuring Mnstrument. vol.49, pp. 20-24, October,2012.

[7] D.G.Jarrett,A.M.Muniz-Mercado and M.E.Kraft. “Automation of 1TΩ to 100TΩ ultra-high resistance measurements at NIST”. 2008 Conference on Precision Electromagnetic Measurements. pp:270-271, 2008.

[8] Drung D, Gotz M, Pesel E, et al. “Aspects of application and calibration of a binary compensation unit for cryogenic current comparator setups.” IEEE Transactions on Instrumentation and Measurement. 62(10), pp:2820-2827, 2013.

[9] Wei Guorui, Zhang Jianguo, Li Long, et al. “Accrate determination temperature coefficient of wire by temperature control digital indication.” Journal of Shanxi Institute of technology. Vol.21, pp:93-94,April,2005.

[10] Qiao Y E, Liang F G, Zheng S Q, et al. “Research on the Verification method of the Agilent B1505A semiconductor device analyzer.” 2013 Third International Conference on Instruentation, Computer, Communication and Control.pp:374-378, 2013.

[11] Dziuba R F, Jarrett D G, Scott L L, et al. “Fabrication of high-value standard resistors.” IEEE Transactions on Instrumentation & Measurement. Vol.48, pp:333-337, 1999.

[12] Wang Yibang, Zheng Shiqi , Liang Faguo, et al. “High precision calibration method for high value resistor with 1MΩ-100GΩ.” Journal of Astronautic Metrology and Measurement. Vol.35, pp:54-56, October, 2015.

[13] Shao Haiming, Lin Feipeng. “An environment stabilized super high resistance and its measurement.” Proc. Of conference on precision electromagnetic measurements. pp:344-345, 2004.

[14] Zheng Huizhi, Wu Zhancheng. “Analyze and research of high resistance measurement.” Journal of Ordnance Engineering College. Vol.18, pp:45-48, Septemper,2006.

[15] Sang Lin, Wang Bin. “Completed equipotential shielded high value resistor.” 2008 academic conference on measurement and testing. pp:270-275, 2008.