AN AUTOMATED SYSTEM FOR THE MEASUREMENT OF HIGH-VALUED RESISTORS

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Abstract

An automated method for measuring high-valued resistors is described. It is based on a loss-of-charge method, involving the discharge of a standard capacitor through an unknown resistor. This system is intended to calibrate standards ranging from 10^{10} Ω to 10^{14} Ω.

Introduction

Currently, NIST provides a calibration service for high-valued resistors from 10^{7} Ω to 10^{12} Ω. However, over the past few years, many requests have been received for services up to 10^{14} Ω. The capacitance-discharge system will support picoammeter, megaohmmeter, and teraohmmeter calibrations, and measurements of insulation leakage, dielectric performance, ionization currents, resistivity of thin films, and very low operational amplifier offset currents in sensitive instrumentation.

Since this system measures resistance in terms of the farad, it allows for an independent check of the NIST resistance scaling process at the high-resistance level. In addition, this is a direct system, relating resistance to capacitance and time interval, without any intervening resistance scaling. Therefore, there is no need for frequent, cumbersome recalibrating of unstable working standards or characterizing the voltage coefficients of such standards.

Theory of Operation

The capacitance-discharge system is a variation of the loss-of-charge method for calibrating high-valued resistance standards. The latter procedure involves the discharging of a capacitor through the resistor over a particular time interval, and measuring the rate of change of the voltage across the resistor. The resistance R_x is determined by the following equation:

$$R_x = \frac{t}{C \times \log(V_0/V_f)} \tag{1}$$

where t is the time in seconds, C is the capacitance in farads, and V_0 and V_f are the initial and final voltages across the resistor, respectively.

There are several variations of this method. [1], [2], [3] In this version, the capacitor of value C_s shown in Fig. 1 is charged to voltage V_s when switch S is closed, so that

$$Q = C \times V_s \tag{2}$$

where Q is the total charge on the capacitor, and V_s is the voltage applied to the circuit.

When S is opened, the capacitor will discharge through the resistance R_x. Because of the large voltage coefficient of many high-valued resistors, the capacitance is decreased slowly at a rate such that the voltage across the capacitor remains constant.

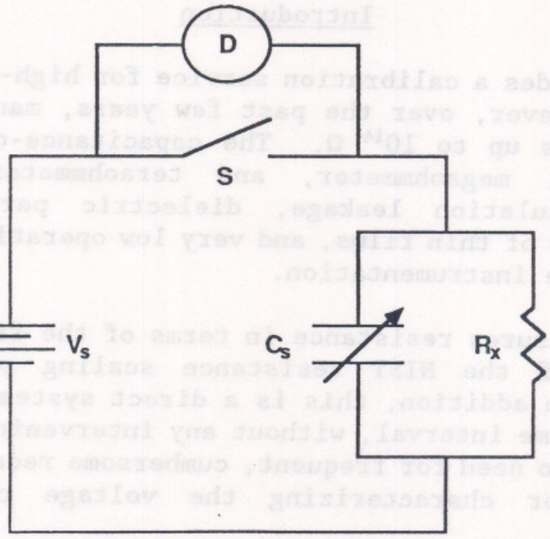

Fig. 1. Discharge Method

This produces a current i = dQ/dt through the resistor. Using Kirchhoff's current law, the equation for the circuit is expressed as

$$V_s \times \frac{dC(t)}{dt} + \frac{V_s}{R_x} = 0. \tag{3}$$

$$\frac{dC(t)}{dt} = \frac{-1}{R_x} \qquad (4)$$

This last equation gives the formula for maintaining the voltage constant by adjusting the capacitance. Integrating it gives

$$C(t) = \frac{-t}{R_x} + C_s \qquad (5)$$

where C_s is the value of the capacitor at time $t = ts = 0$. Assume that the capacitor decreases for time interval $\Delta t = t_f - t_0$. Solving for R_x,

$$R_x = \frac{V_r}{V_s} + \frac{\Delta t}{\Delta C} \qquad (6)$$

where $\Delta C = C_s - C(t)$.

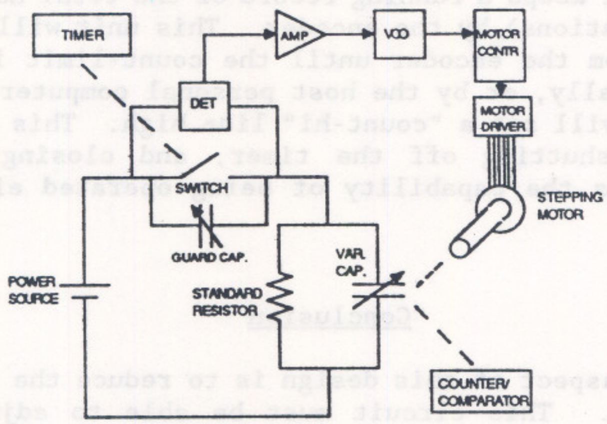

Fig. 2 Capacitance-Discharge System

Design of System

This system is controlled by a feedback network which continually adjusts the rate of decrease of the capacitor at a rate defined by equation (4), and a counting-timing network which monitors the change in capacitance and the elapsed time. These circuits, in relation to the rest of the system, are shown in Fig. 2.

Feedback Network

The potential across the switch S determines the rate of change of capacitance. In order to keep the voltage across the capacitor constant, the potential across the switch must be kept at zero. A high-impedance electrometer measures this potential, and sends its output to a feedback network (see Fig. 2). This feedback network consists of an amplifying and integrating circuit, a voltage-controlled oscillator (VCO), and a stepping motor. The detector output is amplified and integrated and then fed to the VCO. The pulsing output is sent to the motor controller, which translates the pulses into the proper operating sequence for the stepping motor. The motor is connected, via a gear chain, to the shaft of the variable capacitor. Thus when the potential across S begins to increase, the motor will decrease the rate of change of capacitance accordingly.

Counting and Timing Network

The time interval is measured by the time-interval function on a commercial universal counter. The timer is initiated with a start-measurement signal from the host personal computer or a manual-start switch, and is terminated with a stop-measurement signal from the counter/comparator.

The change in capacitance is determined by counting the number of rotations of the capacitor shaft. The counter/comparator detects fractional pulses from an optical encoder mounted on the shaft of the stepping motor.

The counter/comparator keeps a running record of the total number of rotations (and fractions of rotations) by the encoder. This unit will count the number of pulses sent in from the encoder until the count-limit is reached. This limit may be set manually, or by the host personal computer. When the limit is reached, the unit will set a "count-hi" line high. This serves as a stop-measurement signal, shutting off the timer, and closing switch S. The counter/comparator has the capability of being operated either remotely or locally.

Conclusion

The most challenging aspect of this design is to reduce the systematic errors in the feedback loop. This circuit must be able to adjust and hold the capacitor rate such that the potential across switch S deviates from zero by only a few millivolts. The amplifying and integrating circuits of the feedback network must respond quickly enough to keep the stepper motor at the proper speed. Other systematic errors include 1) leakage of charge across the insulation of the capacitor, 2) proper isolation and shielding of the measuring instruments, 3) linearity of the capacitor, 4) accuracy of the timer and counter, and 5) thermal emf in the detector circuit.

The uncertainties for this measurement system will be reported at the conference. It is hoped to offer services to the public at 10^{13} Ω with a measurement uncertainty of 1.0% or better.

References

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[2] A.H. Scott, "Measurement of Multimegohm Resistors", Journal of the National Bureau of Standards, Vol. 50, pp. 147-152, March 1953.

[3] S. Hoi Tsao, "An Accurate, Semiautomatic Technique of Measuring High Resistances", IEEE Transactions on Instrumentation and Measurement, Vol. IM-16, pp. 220-225, September 1967.