APPLICATION NOTE 103

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MEASUREMENT SOLUTIONS

Resolving Milli-Ohm Measurement Errors with the TEGAM Model 1750

Introduction

This application note describes how a customer used the TEGAM Model 1750 High-Speed Programmable Micro-ohmmeter to control the silver plating thickness of copper wire in real-time.

When Milli-Ohm Measurement Errors Become Significant

Basic resistance measurements are relatively straightforward. An ohmmeter is connected across a resistive device, the proper range is selected and a reading is taken from the instrument's display. As the resistance value decreases and the accuracy requirements become more stringent, the art of resistance measurement becomes more challenging. Eventually, the resistance measurement becomes a milli-ohm measurement. In one particular application we learned that milli-Ohm measurements are not always simple. Measuring low resistances on continuously moving wire can reveal sources of measurement error that are not typical.

This particular application required us to measure the resistance of silver-plated copper wire after it moves through an electroplating bath (Figure 1).

A regulated electrical current flows from the wire to the silver bath. The current flow initiates the plating process. The coating thickness is inversely proportional to the speed of the wire as it passes through the silver bath. As the thickness of the coating increases, the resistance of the wire decreases.

Accurate milli-Ohm measurements require the detection of ultra low voltages, usually in the milli to nano volt range. Because lead resistances create significant errors at these levels, we used a four-wire Kelvin lead configuration. The four-wire Kelvin configuration minimizes lead resistance errors by using a regulated current source for the test signal. Voltage sense leads are connected across the sample terminals to measure the voltage across the sample and a final resistance value is calculated. Figure 2 illustrates the fundamental Kelvin measurement scheme.

After the coating process, the resistance of the wire was measured between a set of four-Kelvin electrodes. The wire passed over the I+ and V+ probes, and exactly two feet later the wire passed over the V– and I– probes that completed the Kelvin bridge. We divided the resistance reading by two in order to get the correct resistance per foot. Depending on the plating requirements, the desired resistance of the silver-plated wire typically ranged from 0.050 to 2.000 Ω/ft. The specified variance of the plated wire was ±0.015 Ω.

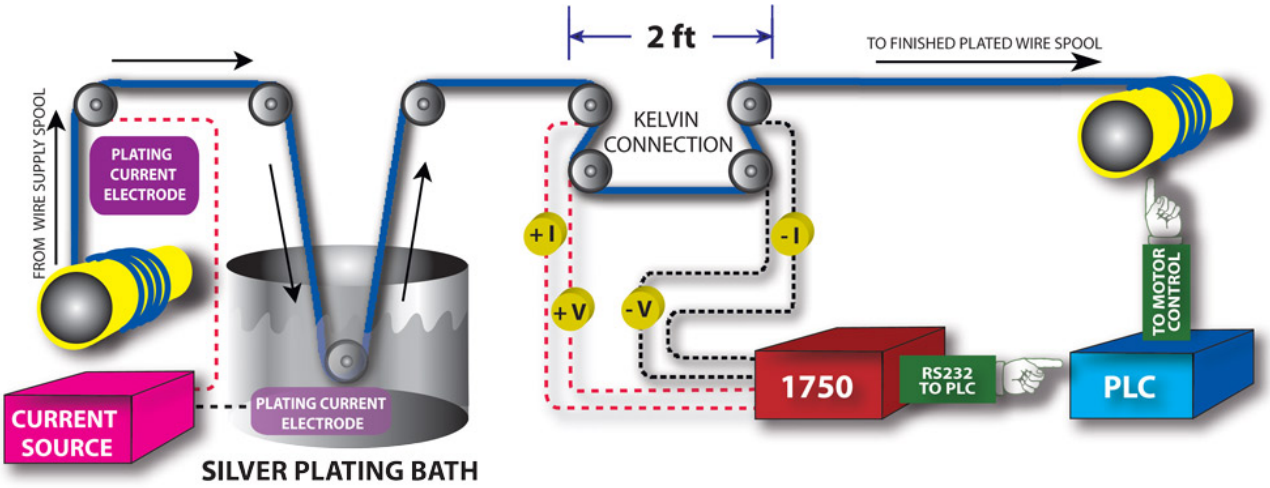

Figure 1 - A wire-plating system uses a four-wire Kelvin connection to measure the resistance of moving wire. An Allen Bradley PLC regulates the wire speed to maintain a constant coating thickness.

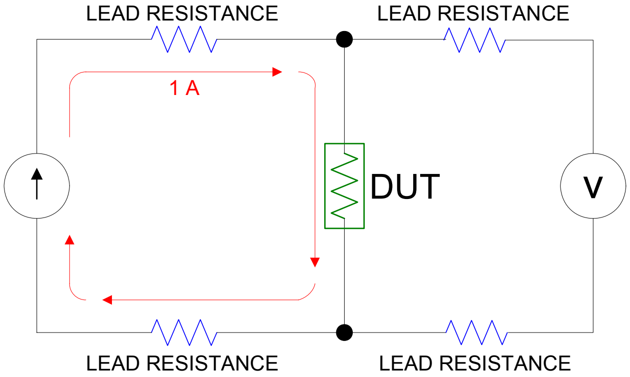

Figure 2 - Electrical representation of a four-wire Kelvin measurement. Use of a current source cancels the lead resistance of the supply leads. Measuring the voltage drop across the DUT terminals minimizes overall lead resistance errors.

Measuring Resistance the Hard Way

Our first approach involved the application of a regulated 100-mA excitation current to the wire. Another signal transducer monitored the voltage across the two-foot wire section. An RTD was used to compensate for ambient temperature deviations.

We used Allen-Bradley analog-input cards with 14-bit resolution, which gave us a 0.003 Ω uncertainty. This was within the ±0.015 Ω variance we were allowed. We calibrated our system and started to plate wire.

For the first batch of plated wire, our instruments measured a resistance of 1.000 Ω /ft, which was our desired outcome; however, the quality lab said the wire was barely within spec; it was consistently on the high side of the 0.015 Ω tolerance. Consequently, what we measured as 1.000 Ω, the lab measured at approximately 1.015 Ω. How could a 0.003 Ω measurement uncertainty turn into a 0.015 Ω measurement difference?

The next day, we put calibration resistors on the line before starting production, but no longer had good readings. The system seemed to lose calibration overnight. We had "fun" recalibrating the system every day before doing our tests only to achieve the same result: To varying degrees, the resistance was always higher than the computer average.

A Shot at Commercial DMMs

Perhaps we had to admit that we could not build our own Kelvin system. We bought an HP 34401A 6 1/2-digit DMM and a Basic module so the Allen-Bradley controller could "talk" to it. Initially, we got encouraging results. The meter read all the resistance standards perfectly and gathering the data through the Basic module meant we no longer had to calibrate the line daily. We tried plating wire again, this time with a resistance of 100 mΩ/ft, but the wire's actual resistance did not match our measurement system readings.

We noticed that the resistance of the wire fluctuated as soon as the line started, even in the absence of the plating current. We changed the DMM to its DC-voltage mode and measured the voltage across the wire. The DMM read 0 V with the wire stationary and then measured a small voltage that increased to about 100 µV as the wire speed increased. This voltage also varied as the curvature of the unspooling wire varied the surface contact of the wire to the probes. We had discovered the problem!

Checking the specs for the HP DMM (in Ohms mode) revealed a 1 mA excitation current. One milliamp of current passing through the 100 mΩ wire produces a voltage of 100 µV, the same amplitude as the mysterious voltage.

A friend who has worked with electricity since the days of Thomas Edison told me that I was observing the triboelectric effect, a fancy name for static electricity. He told me that any time two materials rub together, they generate a small voltage. To overcome the triboelectric effect, we believed the excitation current had to be much larger. Unfortunately, the HP DMM was limited internally to producing a 1-mA current, so we had to choose another instrument.

TEGAM Solves the Problem!

We decided to try the TEGAM Model 1750 High-Speed Programmable Micro-ohmmeter (Figure 3). This unit offered a number of helpful features. First, it provided bipolar excitation. That is, the unit reverses current flow several dozen times a second and averages the readings to improve measurement accuracy. Bipolar excitation cancels thermoelectric junction and triboelectric effects without having to reprogram resistance offsets. The triboelectric current varies with wire speed, size and angle and thermal offsets vary with temperature changes. These leading causes of low-level measurement errors were completely eliminated with the Model 1750.

Figure 3 - The TEGAM Model 1750 is the fastest digital milli-ohmmeter in the industry. Capable of measuring from 100 nΩ to 20 MΩ the 1750 is optimized for automated testing of resistors, fuses, welds, wire bonds, mechanical bonds and other resistive elements. A comparator, control I/Os, RS232, RS422, and GPIB interface are included for compatibility with many common PLC or industrial control types.

Figure 4 illustrates an equivalent circuit for the probe connections across the two-foot length of wire. I_x flows in two polarities, from the ohmmeter current source through the section of wire being measured, R. Depending upon its polarity, I_x, the test current may either add or subtract from the triboelectric current, I_t.

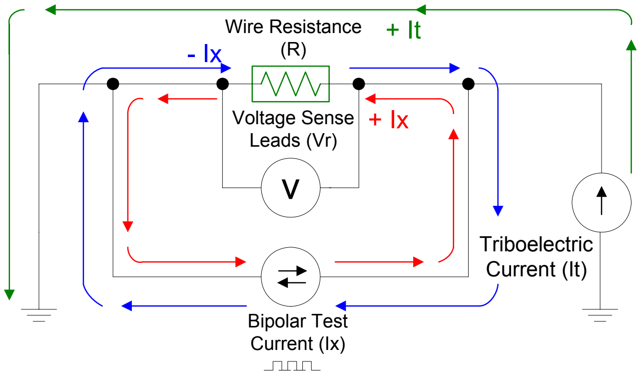

Figure 4 - The 1750 produces a bipolar test current up to 1 Ampere in magnitude. The test current drops a voltage across the wire resistance ± (I_XR), which depending upon polarity, either adds to or subtracts from the triboelectric voltage drop, (I_tR). The1750 then averages the net voltages and outputs a corresponding resistance value at the 1750 RS232 port.

If I_x is unipolar as in many ohmmeters, then an erroneous resistance reading will be measured. However, in the 1750, I_x is bipolar and an averaging technique, which cancels the triboelectric offset, is used to produce a highly accurate resistance measurement. The bipolar averaging is performed as follows:

For the Voltages across R:

For $+I_x$: $V_{R1} = I_tR + I_xR$
For $-I_x$: $V_{R2} = I_tR - I_xR$

For the Average Resistance:

$$R_{AVE} = \frac{V_{R1} - V_{R2}}{2\,I_X}$$

The TEGAM Model 1750 also had a number of features which made it easy to integrate with the AB controller. These included TTL and relay outputs and an RS232 port, which made it really convenient to communicate to the AB controller. We quickly reprogrammed the Basic module to communicate with the TEGAM unit. The 1750 would send continuous streams of resistance data to the controller while the speed of the wire was adjusted to regulate the coating thickness.

We set up the measurement system for 100 mΩ wire and started the plating line, quite pleased that the reading did not jump when the wire started moving. We took the finished roll to the quality lab and it was right on spec. Through first hand experience we learned that milli-Ohm resistance measurements may not be as clear-cut as theory suggests. By design TEGAM's Model 1750 helped us resolve milli-Ohm measurement errors in practical applications that we would have otherwise not expected.

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