How a Micro-Ohmmeter Aids Compliance with UL2556

This application note describes how a micro-ohmmeter with offset voltage compensation can assist a manufacturer or processor of electrical wire to cost effectively meet the DC Resistance measurements requirements of UL2556. UL2556 is the harmonized tri-national standard and successor to UL1581 which specifies the measurement and test methods for flexible cord and power wire products that are covered by UL standards 44, 62, and 83.

Background

The American Wire Gauge (AWG) was derived from a geometric standard created by Brown and Sharpe in 1855. It started at 4/0 wire with a diameter of 0.46" and the next lower wire size was derived by multiplying the diameter by 0.890526. These became tabulated into what we call the AWG ranging down to 40 gauge wire at 0.003" in diameter. While a mechanical standard is useful for physically sizing wire, the primary concern for electrical conductors is current carrying capacity which is driven by the resistance. In the past it has been a reasonable assumption that if wire was made of electrical grade copper the resistance was correct if the mechanical dimensions were also correct. Like many assumptions, it can end up costing a significant amount of money when the underlying conditions change.

Why Is It Necessary?

In today's global economy materials enter the supply chain from several sources. Recently a US wire manufacturer was involved in a lawsuit when a machine caught fire due to undersized wire. In fact, the wire was counterfeited in China with incorrect AWG markings and the US manufacturer's trademark duplicated on the wire. To protect themselves in the event of another lawsuit, a resistance measurement system was implemented to certify that all wire produced met the DC resistance specifications.

Copper is expensive. If wire is oversized by 3% to ensure that the minimum resistance specifications are achieved without verification then it results in an additional cost of $1 per 1000' of 14 AWG at current copper prices. At a wire drawing speed of 20m/sec that is over $1600/day of lost profit for just one drawing line.

Accurate DC Resistance Measurements

The process of measuring DC resistance seems to be relatively simple. The initial reaction is to take a handheld ohmmeter and perform the measurement. This works fine for relatively high resistance measurements but is completely inadequate for the low ohm measurements needed when working with wire specimens. This is because the leads of the ohmmeter become a significant portion of the overall resistance and result in an inaccurate reading. This measurement method is known as the 2-terminal method. This is illustrated in Figure 1.

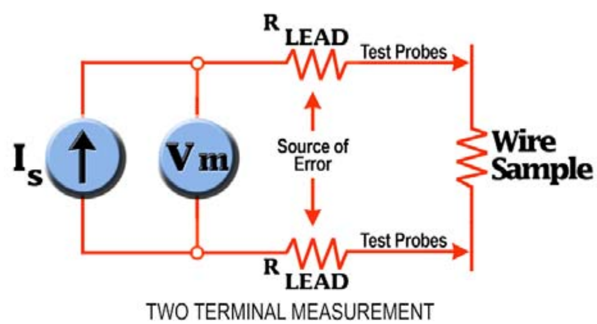

Figure 1 – The measurement method known as the 2-terminal method is subject to error introduced by R_{LEAD}.

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The ohmmeter applies a known current through the leads and measures the resultant voltage to determine the resistance value. UL2556 specifies a 4-terminal measurement when working with resistances of less that 1 ohm. A 300mm piece of wire at every gauge except 40 is less than one ohm. An alternative is to measure very long lengths of wire in order to increase the resistance value and make an accurate 2-terminal measurement. There are two difficulties with this approach. First, a thousand feet of #10 AWG is still less than 1 ohm and the length must be known to within 0.1%. Secondly, measuring a long length of wire averages the resistance over the entire length. There could be lengths of wire in the midst of the whole piece that do not comply.

Figure 2 illustrates a 4-terminal measurement. The advantage of this method is that the current supplying leads are separated from the measurement leads. Any error introduced by the current leads is ignored by the measurement system.

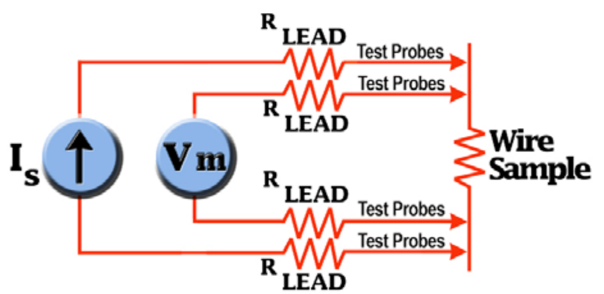

Figure 2 – The 4-terminal method is widely recognized as the preferred form of measurement.

One method of implementing a 4-terminal measurement is the Kelvin Ratio Bridge. The bridge functions by comparing a known resistance to the measured sample. Any difference between the reference and measured sample is seen as an imbalance in the bridge. The bridge is adjusted to restore balance and the actual resistance of the test sample is calculated from the amount necessary to rebalance the bridge.

Unfortunately for the user, bridges cost more than $30,000 and are intended for use as metrology instruments in a laboratory. The measurements are very precise but the rate of measurement is not very high. These would be used on a sampling basis where a piece of wire would be periodically taken from the processing line and tested in an environmentally controlled lab. Both Guildline Instruments and Measurements International are manufacturers of highly accurate resistance bridges.

Another approach is to use the traditional micro-ohmmeter. These instruments have been used in the utility industry to measure circuit breaker contacts and bus bar connections as well as other low resistance circuits. These instruments combine a stable high current DC source and a voltage measurement circuit. In principal they apply a known DC current to the unknown resistance, measure the voltage and compute resistance. However, it is often the fringes of experience that demonstrate the fallacy of our assumptions and low resistance measurements are certainly on the fringe. It is necessary here to digress and discuss the effects of thermal electromotive force (EMF) in connections.

The Thermal EMF Problem

Thermal EMF is the term for the voltage created when two dissimilar metals are brought in contact. This is also known as the Seebeck Effect. This voltage can be significant depending on the metals and their temperature and can produce a measurable error. The typical micro-ohmmeter has several connection points in the measurement path that produce thermal EMF errors. At a minimum there are the instrument jacks where the test leads connect and the contact point where the leads touch the sample. It is quite likely that the voltage drop produced by these connections is as much as 1 mv. In contrast, a 1A current flowing through a 300mm piece of #12 copper wire results in a 1.59mV signal. If the 1mV error produced by the connections is not corrected for, the final resistance reading will be off by more than 60%. To solve this problem the traditional micro-ohmmeter uses the graduated hammer principal of engineering. That is, if a small hammer doesn't work then try a bigger one. In this case, this is accomplished by applying larger test currents to swamp the error caused by the interconnections. It is not uncommon to see micro-ohmmeters with 200A current sources to produce acceptable readings at low resistances.

The Right Way

Figure 3 – The TEGAM Model 1750.

The TEGAM Model 1750, Figure 3, utilizes a 4-terminal measurement with an offset compensated ohms measurement to quickly and accurately measure low resistances without the bulk and expense of a large current source. Offset compensation is a technique that applies current in one polarity and measures the resultant millivolt signal. The current polarity is then reversed and the measurement is taken again. If the two readings are mathematically combined it results in a cancellation of the thermal EMF effect. A more thorough explanation of the process is contained in TEGAM's Application Note AN103: Resolving Milli-ohm Measurement Errors with the TEGAM Model 1750, available at www.tegam.com.

The exceptional measurement performance of the Model 1750 enables it to accurately measure 1 foot wire samples from 1000MCM welding cable to #40 gauge wire in copper or aluminum. This makes it useful to wire producers and processors as a check standard for periodic monitoring of production. However, the Model 1750 offers an additional capability not found in any other micro-ohm measurement instrument. It has the ability to make a measurement in 10 msec! This means that the Model 1750 could be used to monitor a wire drawing stand in real time up to 30m/sec; thereby ensuring 100% inspection of wire gauge conformance and permit the minimization of wire usage by dynamically tuning wire drawing parameters. The Model 1750 includes convenient communications and a PLC interface for straightforward implementation into existing wire drawing stands.

For more information about the TEGAM Model 1750 High-Speed Programmable Micro-Ohmmeter contact TEGAM at 1-800-666-1010 or visit our website at www.tegam.com