On the problematic of Linear Resistance Measurement of Aluminium conductors

or how to interpret the measurement results

INTRODUCTION

The measurement of the electrical linear resistance of stranded aluminium conductors always raises a debate when interpreting the test results.

Consequently, Understanding the fundamentals of the measurement is necessary for a correct interpretation of the results.

OXYDE LAYER AND CURRENT DISTRIBUTION

The linear resistance measurement (R/d) is based on the well-known Ohm's law

$$R = \frac{(U/d)}{I}$$

i.e. a current (I) is injected in the conductor (of resistance R) and the voltage drop (U) over a given distance (d) is measured. Further considerations on temperature that have to be taken into consideration in the final result do not affect the rational given here.

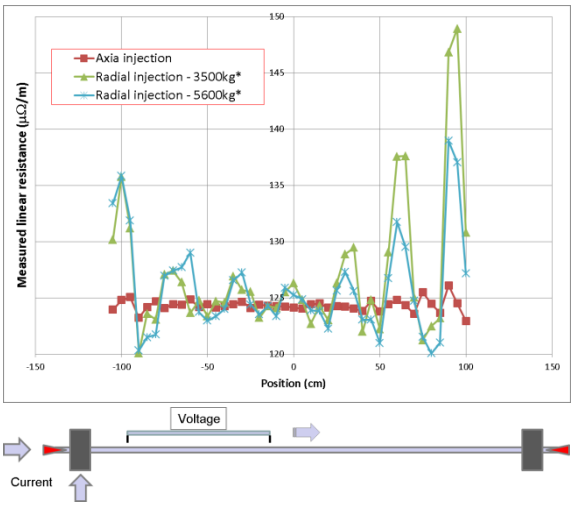
As the voltage drop is measured on few wires of the outer layer of the conductor only, a prerequisite for the validity of this equation for multi-wire conductors is that the current must be distributed homogeneously in the whole cross-section of the conductor, i.e. each wire (supposed to be of the same electrical cross-section) has to conduct the same amount of current, so the voltage drop over a given length is identical for any measured wire.

This is where the problem arises with aluminium conductors: the insulating aluminium oxide layer, that quickly forms on the wire surface, hinder the homogenization of the current among the wires. And this current is usually injected through contacting jaws on "a restricted number of wires" on the outer layer of the conductor.

INTERPRETATION OF THE MEASUREMENTS

The voltage measurement reflects the current circulating in the outer wires in contact with the voltage taps.

This can be clearly seen on the graph below where the voltage has been measured on a 240mm^2 aluminium conductor using our ResTest 210. Measurement has been performed at different positions by moving the voltage ruler along the conductor, thus contacting different wires for each measurement.



The blue and green curves show measurements using radial injection with different compression forces on the contacting jaws. The red curve shows results for axial current injection. Note that the period of the observable oscillations corresponds exactly to the lay length of the wires in the outer layer.

One can noticeably see that:

- Some wires conduct more current than others: measured voltage drop is higher at repetitive intervals corresponding to the wires lay length;
- The current tends to homogenize along the cable length: the oscillations become smaller at the centre of the conductor;

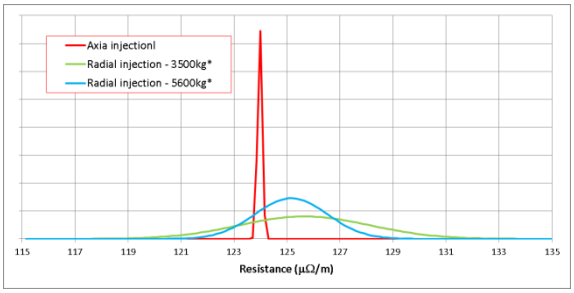
- The current is slowly penetrating the inner layers: the mean value of the curves tends to decrease at the centre of the conductor;
- Increasing the force applied on the jaws improves the initial current distribution by lowering the inter-wire contacts resistance;
- Injecting the current axially almost supresses the periodic oscillation effect as the current is practically injected homogeneously in the whole conductor cross-section.

This clearly indicates that the contacts from the current injection system to the different wires are not equivalent. Additionally, the current has the tendency to flow along the individual wires rather than distribute through the whole conductor.

The distance between current injection and voltage measurement is thus an important parameter that can strongly impact the current homogeneity at the voltage measurement position. Injecting the current homogeneously is the best way for improved measurement accuracy.

It also demonstrates that, depending on the position of the voltage measurement, the measured value can be lower than the actual one. Hence, **A LOW MEASURED VALUE IS NOT THE SIGN OF AN ACCURATE MEASUREMENT!**

As the real linear resistance of the cable under test is not known, the only reasonable way to qualify the validity of the measurement is to look at the width of the distribution of a set a measurements made at different positions (by moving the voltage taps or changing the conductor position). This is shown in the below figure for the same set of measurements.



Current injection	Radial	Radial	**Axial**
Clamping (kg*)	3500	5600	**1400**
Pulling (kg*)	1400	1750	**350**
Mean value mΩ/m	125.65	125.15	**123.97**
Std Dev.	1.97%	1.09%	**0.07%**

A narrow distribution is the sign of a good current homogeneity and hence higher accuracy. As expected, axial current injection provide the most accurate result with the smallest standard deviation.

CONCLUSION

The interpretation of linear resistance measurement on aluminium conductor is far from being obvious.

The aluminium oxide layer on the surface of the wires mitigates current homogeneity and may strongly affect the measurement results.

Unlike common perception, lower measured value cannot be solely attributed to improvement of the electrical contact during the measurement, but may reflect uneven current distribution in the conductor.

It is then important to repeat the measurement in different configurations and check its reproducibility which is a reasonable way to qualify/quantify its accuracy.

Boris Dardel, R&D Director, AESA Cortaillod