Proficiency in linear resistance measurements

or overall accuracy of linear resistance bridges

This note focuses on the metrology. It doesn't discuss the need to integrate linear resistance bridges in the supply chain of power cables, assuming that the readers have by now accepted the crucial importance of such measurements, in order to actively save material costs and at the same time demonstrate the conformance to specifications, all along the procurement chain, in the production, the internal and external quality laboratories and at incoming inspection by the end users.

Overall accuracy is of essence to ensure low material safety margins but also for reliable comparisons between test laboratories by sharing compatible methods and fully traceable standards.

ISO 17025 accreditation is due to demonstrate the metrological abilities and knowledge and IEC60468 sets the details of the accuracies to be achieved for each influencing parameter. Overall accuracy results from the compilation of the uncertainties.

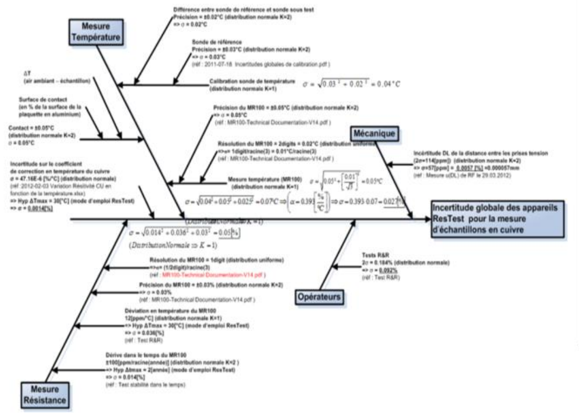

Fig 1 Ishikawa diagram
for the analysis of uncertainties by testing copper samples

Fig.1 shows a typical example of establishing an uncertainties' budget in an Ishikawa diagram. The standard deviation is calculated from the square root of the sum of squared uncertainties.

$$\sigma = \sqrt{u_{Cu}{}^2 + u_{\Omega}{}^2 + u_T{}^2 + u_L{}^2 + u_{op}{}^2}$$

The four main factors contributing to measurement error are the following :

- **Resistance measurement**: A modern ohmmeter compensates for the residual voltages stemming from thermal EMF voltages and from offset voltages of the electronics. Its contribution to overall error should consequently be low.
- **Temperature**: measuring an exact temperature of the sample is not an easy task. Long time waiting on stabilization at the room temperature is a stopgap, often luxurious for the practical handling of the devices without being sure one gets the right value. Best is a measurement integrated into the test system which allow for an automatic correction to the reference temperature. Fortunately the sensitivity of resistance to temperature (around 0.4% per °C) gives a good indication of the stabilization, provided the sensor is integrated and one disposes of a graphical representation of the results (e.g. Fig.2).

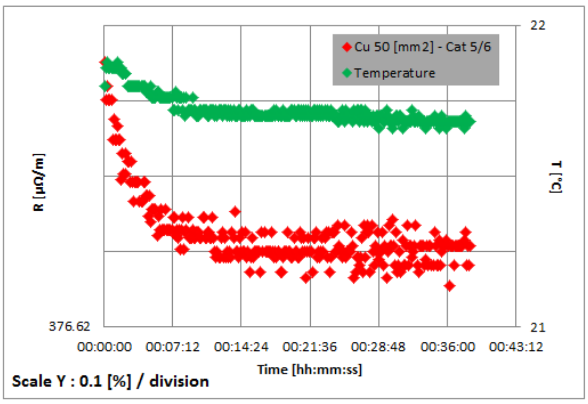

Fig 2 Resistance and temperature courses during stabilization.

- **Length** between the voltage taps is often a dangerously neglected factor of error. Best here is a regular check of the system with a certified calibrated rod and the integration of the corresponding correction factor in the system's control unit in order to minimize the residual uncertainty.
- Remains than the **precision** of the measurement, i.e. its repeatability and reproducibility. Three factors determine this uncertainty of contacting the conductor:
  * type and condition of the conductor.
  * suitability of clamping system.
  * operator handling.

In fact, because of the quadratic function of the overall accuracy, the differences between uncertainties are amplified and this last factor is most often the critical contributor to the global standard deviation. The challenge behind contacting the cable under test (CUT) is to inject the current with an exact homogeneous distribution in the entire section.

We know that contact resistances between the wires constituting the cable are the key factor preventing the homogeneity-cf.ref.1-. They lead to issues of stability and reproducibility of linear resistance measurements.

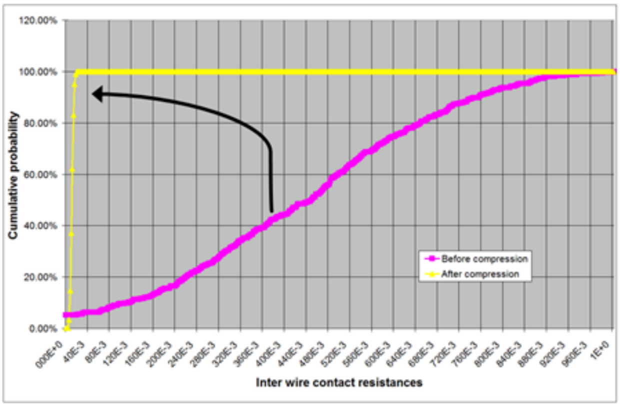

Fig 3. The contact resistance depends strongly on applied pressure

While Class 1 and Class 2 copper conductors – cf. IEC60228- are made of limited number of thick wires and are easy to test with nearly any kind of clamping devices. Aluminium strands begin soon to present difficulties which increase when the section grows because of the oxide layer forming already at low temperatures. But problems can also occur with large copper cables depending on the condition or age of the CUT, including the utilization of specific substances during their manufacturing. Class 5 or 6 conductors are, to achieve their flexibility, made from a large number of thin wires and this configuration amplifies drastically the problems one may encounter at characterizing them.

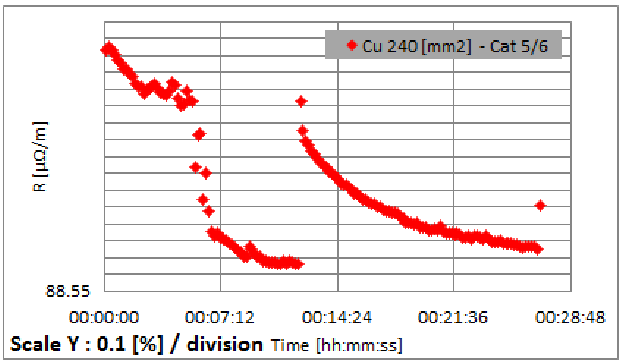

Fig 4. Instabilities in measurement s due to inter-wires contact resistance

The best way established so far to master corresponding metrology is to increase the clamping pressure and even to rethink the shape of the clamping jaws as needed. We have developed the ResTest 100 to that aim.

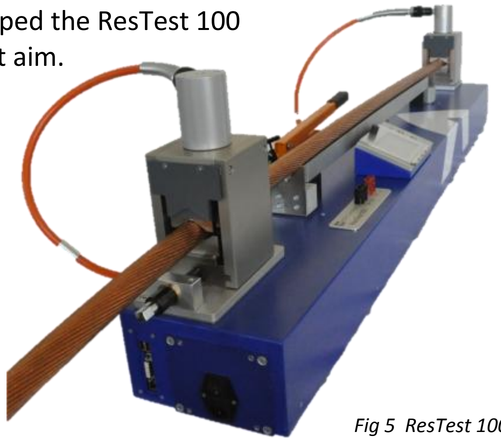

Fig 5 ResTest 100

Hydraulic clamping systems have been designed to apply a force up to 50’000N (5 tons).

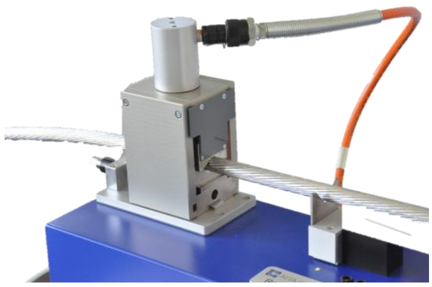

Fig 6. Hydraulic clamping block

The force is adjusted precisely allowing for an excellent reproducibility. A tensioning tool helps replicating controlled test conditions.

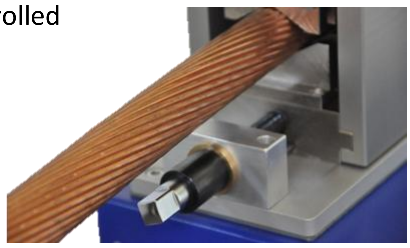

Fig 7. Cable tensioner system

This concept has been worked out for years already with the on-line resistance bridge AESA 8135 with widely recognized success for the measurement of large strands.

Fig 8. AESA 8135 “on-the-line” Resistance & cross-section measurer

We bring now the solution to the laboratory. The commonly utilized teeth jaws have been redesigned to accept a very broad range of conductors and of course to resist to the pressure we may applying.

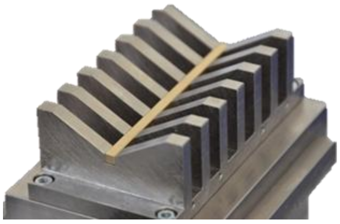

Fig 9. New teeth jaw

Despite the special design, Class 5 and 6 conductors can suffer from too high clamping forces while their conception and their condition may require them. The most common effect is that single wires get cut by the teeth, altering the results. We therefore followed up on the ResTest 50 experiences and created so called compacting jaws allowing the characterization of the trickiest samples

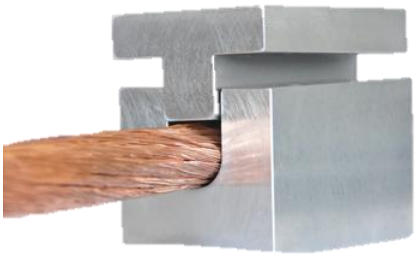

Fig 10. Example of compacting jaw

Each user will build its own expertise base on which clamping force is most suitable in function of the type and the specificities of the cable to be tested, including its condition.

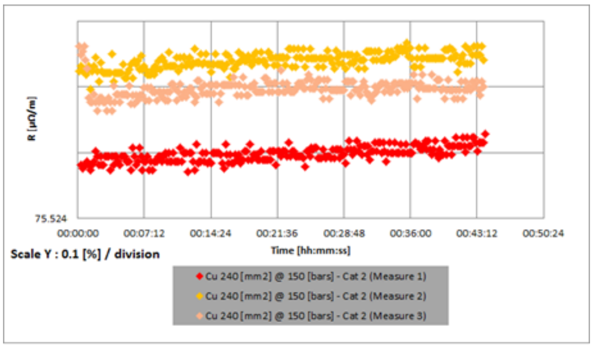

Fig 11. Reproducibility even with most tricky conductors

We have worked out as a first attempt a diagram showing for a given section the recommended force to obtain reliable results without destroying the strand. It may request compacting jaws for the larger Class 5 and 6 cables and is due to be only a help without replacing own experiences (see Fig.12).

Achieving high accuracy of linear resistance measurement of power cable requires besides a high quality ohmmeter, integrating the control of most influencing factors like temperature and length into the Test System. Remains the most crucial parameter, operational handling and proper contacting of the conductors. The ResTest 100 offers now a unique unmatched set-up to get control of your metrology.

Patrick De Bruyne, Executive Chairman, AESA-Cortaillod

References

1. **Effects of Contact Resistances in Multi-strand Cables on Linear Resistance Measurements www.aesa-cortaillod.com**
2. **ISO 17025 and ILAC agreement**
3. **IEC 60468**
4. **IEC 60228**

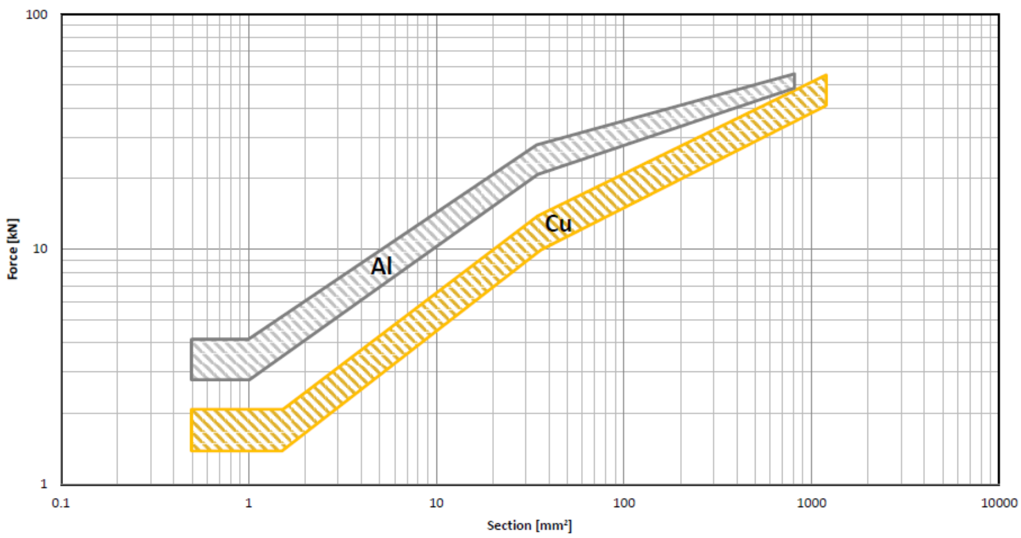

Fig.12: Attempt of recommended clamping force in function of section and material