Technical article

Effects of Contact Resistances in Multi-strand Cables on Linear Resistance Measurements

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Abstract
It is often difficult to overcome errors and instabilities while measuring the linear resistance of multi-strand cables and cords. It is demonstrated here that the main issue stems from inter-wires contact resistances. A new contacting method has been developed allowing mastering this metrological task.

Résumé
Il s'avère souvent ardu d'éliminer erreurs et instabilités lors de la mesure de résistance linéique de câbles ou de cordes multi-brins. Ce travail démontre que le problème principal est provoqué par les résistances de contact entre fils. Une nouvelle méthode de test a été développée pour maîtriser cette métrologie.

Zusammenfassung
Es erscheint oft nicht einfach Fehler und Instabilitäten bei der Messung von linearen Widerständen an Litzen zu vermeiden. Es wird hier gezeigt dass das Hauptproblem von den Kontaktwiderständen zwischen Adern stammt. Eine neue Messeinrichtung ist entwickelt worden um diese Messaufgabe zuverlässig zu meistern.

Introduction

Performing accurate and stable resistance measurements on electrical cables reveals often difficult despite technical specifications that several suppliers of measuring bridges are publishing.
This is particularly the case with multi-strand isolated cables, for which significant errors and instabilities can be observed.
It has been demonstrated that the issues stem from the contact resistances between the wires within the cable or the cord. Different corrective measures are discussed and a new compacting system is presented which allow mastering the task.

Measuring Cable Linear Resistance

Fig.7 shows the measurement of a fourteen years old multi-strand cable over time. Values are unstable and the real cable resistance is at best difficult to determine.
The resistance measurement accuracy depends on an even distribution of the current between the wires. All measuring bridges utilise the Kelvin method, meaning that the current is injected in two points and separate potential taps, placed usually one meter from each other, give the voltage value allowing calculating the cable linear resistance (Ω/km). The sample temperature has a significant influence of the measured values with temperature coefficients of the usual materials copper or aluminium being of the order of 0.4%/K.

Commonly accepted explanation for the incurred problems is that the current needs a long enough distance to distribute itself uniformly. This is not wrong but the order of magnitude of this effect often prevents explaining the observed disturbances. Fig.1 shows the result of simulations for the current distribution in a copper rod when injecting the current punctually. With a distance between current injection and potential tap larger than four times the diameter, the lack of uniformity is negligible. It is far shorter than all practical realisations of measuring bridges.

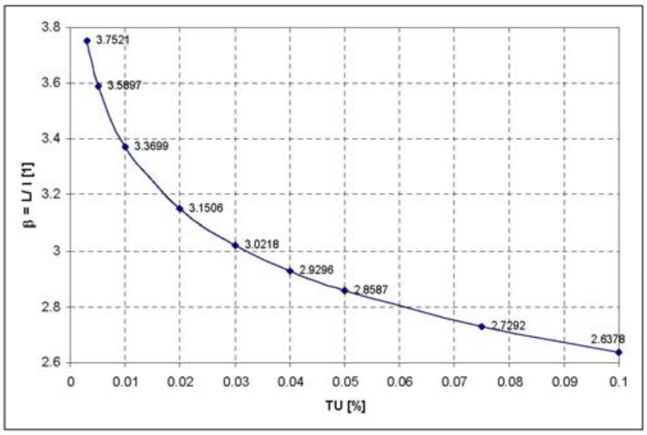


Fig.1 Rate of irregularity of current distribution in a copper rod against the distance from current injection point

Limitations of Measurement Accuracy and Stability

We studied the effects of contact resistance between the wires of a cable. They provoke uneven distribution of the current. Depending on which of these wires the potential taps are connected to, the results can give lower or higher values compared to the nominal linear resistance of the cable. Increasing the distance between current injection points and potential taps just increases the probability of better contact spots but barely eliminates the problem.

Electrical contacts are well described in the literature. They are realised by contact spots and the resistance of the contact is influenced by both constriction resistance (see Fig.2) and by isolative layers stemming from pollution and oxidation.

In particular, oxidation increases drastically the contact resistance as shown in Table 1. With copper, Cu_2O highly resistive film is produced over time even at room temperature. After 1000h at 20°C, a 2nm film is formed on copper with a resistivity 300 times higher than copper resistivity. After 11 years, the film resistivity is 1600 times higher than the one of copper

Aluminium is even much more sensitive. In contact with ambient air it creates instantaneously a Al_2O_3 oxidation film of 2-4 [nm] on the surface which insulates and thus protects the inside of the aluminium against deeper oxidation. The Al_2O_3 has a resistivity of $10^{12} - 10^{14} [\Omega \cdot m]$.

If the isolative film is eclectically insulating or only weakly conducting, a good electrical contact is established only if the film is mechanically disrupted to allow the formation of metal-to-metal junctions.
Indeed applying a force on the contact is expected to have a positive influence both on the constriction resistance by multiplying and widening the contact spots and on the isolative layer by disruption of the film.
Fig.3 shows the expected behaviour of the contact resistance when applying a pressure on the contacts

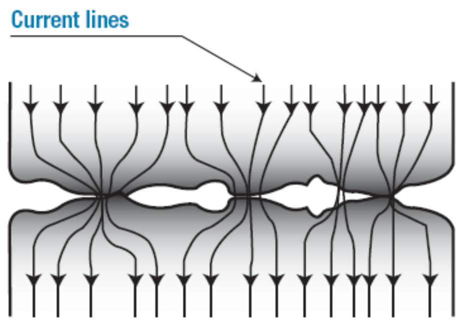
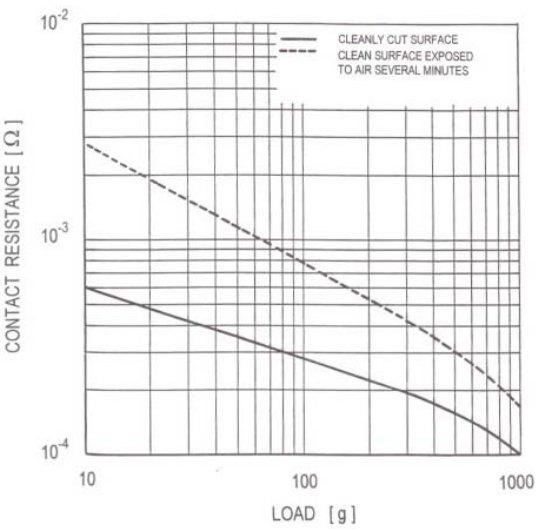


Fig.2 Contact spots result in constriction resistance

Material	Contact resistance	
	New	Oxidised
Pure silver	6 μΩ	25 μΩ
Gold	31 μΩ	31 μΩ
Copper	29 μΩ	400 μΩ
Brass	370 μΩ	1 400 μΩ
Silver-nickel $_{85/15}$	23 μΩ	60 μΩ

Température °C	Thickness (10^{-10} m)	
	After 1 000 h	After 100 000 h
20	21,7	37
55	35	170
60	39	210
85	87	690
100	150	1 300

Table 1 & 2
Influence of oxidation and formation of Cu_2O layer



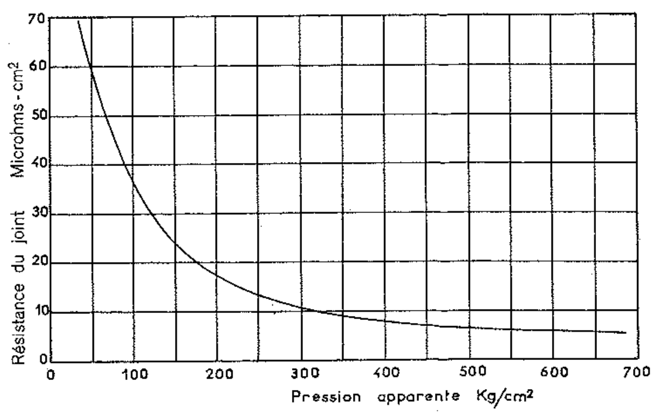


Fig.3 Contact resistance in function of applied force

Corrective Measures and Measuring Systems

Empirically, resistance bridges manufacturers have taken the influence of contacting systems on the metrological reliability into account. For rods and cords, different systems exist covering different ranges of sample diameter (see Fig.4 and 5). Unfortunately some suppliers still indicate in their technical specifications and data sheet the geometrical range as limits for the measuring range despite the fact that in reality the ability of the jaws to disrupt the isolative films represents the real limitation for reliable measurements, in particular for cords and cables made of aluminium or older ones made of copper.

Fig.4 shows a resistance bridge able to test rods and cords up to a section of 630mm^2 and ensuring reliable testing of 300mm^2 aluminium and 630mm^2 copper samples.

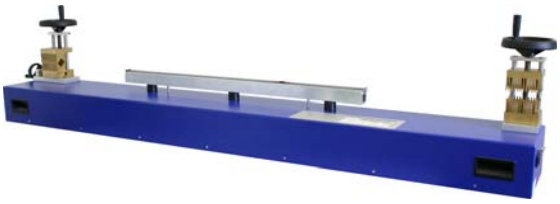


Fig.4 Resistance bridge 7198 (Photo AESA)

In Fig.5 a resistance bridge with hydraulic jaws allows on line testing of aluminium cords up to 1200mm^2 and copper cords up to 1800mm^2 in production. The geometrical limitation is in this case 2500mm^2.

Fig.5 Resistance and Cross section Measuring bridge 8135 (Photo AESA)

The measurement of isolated and in particular multi-strand cables has always been difficult because of the necessity of self-cutting contacts to avoid influencing the measuring values and has shown the most problems in obtaining stable and correct measuring values. We investigated the problem of inter-wires contact resistance on such cables and the effectiveness of a compacting system allowing applying a significant force on the strands without stripping the cable.

Table 3 shows the results in short. The average contact resistance (Rc moy) is 40 times lower and the standard deviation (σ) is 85 times lower resulting in a 37 fold improvement in accuracy (ε moy).

Rc moy	441E-3	[Ω]
σ	240E-3	[Ω]
Rlinear_moy	17.27E-3	[Ω]
ε moy	-3.06	[%]

Rc moy	10.95E-3	[Ω]
σ	2.82E-3	[Ω]
Rlinear_moy	17.80E-3	[Ω]
ε moy	-0.08	[%]

Table 3 : Contact resistance between wires of a 14 years old copper cable B. Soflex T-Litze H05V-K, on the left without compacting and on the right with compacting system.

Fig.6 shows the drastic reduction of contact resistances spread within the cable when compacting it.

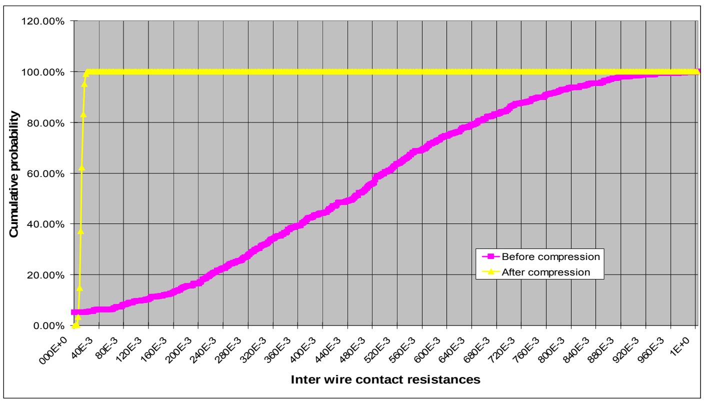


Fig. 6 Statistical distribution of contact resistances

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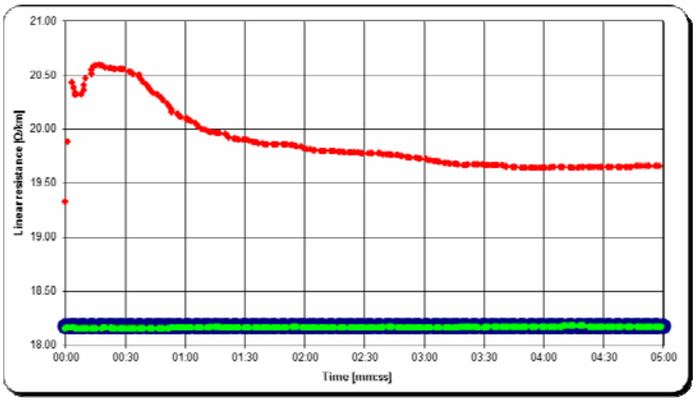

Fig.7 Multi-strand cable measurement on a resistance bridge

Fig.7 gives a comparison of linear resistance measurements (same sample) using or not a compacting system.
* without compacting system (red)
* with compacting system (green)
* reference value (blue)

It demonstrates the instability of the test and the inability to obtain an accurate result without compacting system, for that type of cable.

The graph shows the linear resistance in Ω/km versus time in min. Results are self-explanatory.

This new method is the only one known presently to measure isolated cables with the requested accuracy. Out of 150 cables tested, about ten presented metrological problems with conventional methods which all disappeared thanks to the new system.

Conclusion

We successfully developed a new resistance bridge allowing for the reliable measurement of the linear resistance of cords and multi-strand cables, which was not possible up to now.
It is advisable to metrology engineers to rely on manufacturers understanding deeply and practically the application and the physics behind these measuring tasks and to investigate beyond the indications in the data sheets.

This new method allows characterising small sections (say <30mm2) multi-strand isolated cables for which no reliable linear resistance measuring equipment was really accessible up to now.
Furthermore the described phenomenon explains testing limitations for cords with larger cross-sections and provides hints on how to overcome contingent measuring issues.

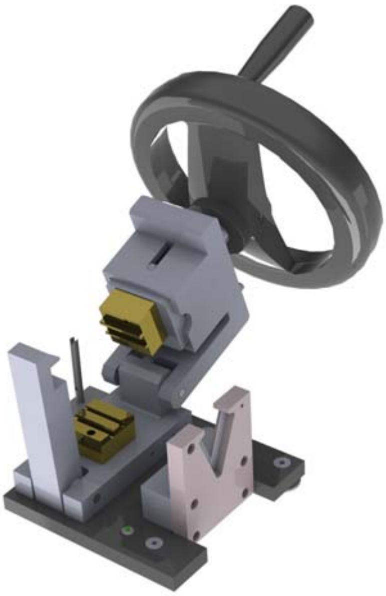

Fig. 8
Compacting system and self-cutting potential taps
(Photo AESA)

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