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Report of ASG JT-60SA electrical tests carried out in ENEA Superconductivity lab

Project Details	*This document is issued for the execution of the Agreement of Collaboration (AoC) between Fusion for Energy (F4E) and ENEA for the supply of 9 TF coils of JT-60SA*	
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Abstract	The measurements, carried out by ENEA Superconductivity lab., of the electrical resistance of the inner joint sample and two terminations manufactured by ASG Superconductors are reported.	

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AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Report on:
JT-60SA Joint Resistance Test.

C. Fiamozzi Zignani

July, 8th 2013

Title	**JT-60SA joint resistance measurements**
Author	**C. Fiamozzi Zignani**
Scope	Scope of the tests was to measure the electrical resistance of the inter-pancake joint prototype, manufactured by ASG, for the JT-60SA toroidal field (TF) magnets.

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Signatures	Chiarasole Fiamozzi Zignani		Antonio della Corte

Measurement set up

For the test of the JT60SA praying hands joint manufactured by ASG, a dedicated facility as been developed at ENEA in Superconductivity Laboratories.

The NbTi joint was fed by High Temperature Superconducting (HTS) 20kA Current Leads designed by CRPP. The copper terminations of the joint, manufactured by ASG as well, have been attached to the current leads cold ends by means of indium pressure connections (Figure 1). The joint and the leads have been inserted in a dedicated cryostat, whose flange has been equipped with liquid and gas helium inlets and with necessary signals connectors.

The testing conditions require the joint to be submerged in liquid helium and afterwards fed with several current plateaux up to 20kA. No background field is envisaged for the joint resistance test.

The cryostat has been instrumented with a Cryogenic liquid helium probe to verify the complete covering of the JT60SA sample (which correspond to 630mm of liquid helium). Two Cernox thermometers, calibrated by Lakeshore, have been placed upon terminations to monitor the temperature of the joint during measurements.

During measurements, the HTS current leads were cooled by means of helium gas flow supplied by a dedicated cryogenic circuit capable to provide flows up to 1.2g/s with temperatures from 20K up to 90K . Helium gas feed the leads heat exchanger and comes out from the leads' heads before reaching the mass flow meters. The HTS current leads have been instrumented with several thermometers and voltage taps in order to monitor their behaviour during current plateaux and to protect them from thermal runaway and quench. In the sketch in Figure 2, all voltage signals and temperatures from leads and joint which were acquired during measurements have been indicated.

A dedicated Data Acquisition System (DAS) has been developed at ENEA in order to observe and acquire signals during measurements. In particular a specific National Instrument (NI) LabView 9.0 VI has been implemented which displays the temperatures, the He flows and the voltages behaviour during cool down and registers the data from each measurement.

The joint resistance has been obtained by means of four probes measurements. Two couples of voltage taps were soldered by ASG on the cable jacket on the two sides of the NbTi joint. Voltage signals, helium flows and differential pressures in the current leads heat exchanger, as well as part of the thermometers, were acquired by means of a NI SCXI device, connected to the acquisition PC by means of a SH 6868 cable. The acquisition PC mounted both a NI PCI 6052E board and a GPIB board; most of thermometers were in fact read by means of 2 Lakeshore 218 devices in which the proper calibration curves have been uploaded for each Cernox or PT100 sensor. During all measurements, both the HTS modules and the heat exchangers of current leads were protected from quench by means of a dedicated quench detector device which monitor the voltages across the HTS module and the heat exchanger of both current leads. This tool has been implemented in order to be capable voltage thresholds arrangements from 3 to 200mV. When the threshold is reached, a signal is send to the power supply, which is shut down within less than 100ms.

Measurements results

Several measurement campaigns have been performed on the JT60SA joint, in order to evaluate its resistance. In the following, a significant selection of the analysis performed on acquired data is shown. The post processing has been performed by means of OriginPro 8 software.

The measured JT60SA joint resistance is 2.25±0.15nΩ.

For the determination of the joint resistance, we only took into consideration those measurements in which the helium level inside the cryostat was at least enough high to completely cover the joint.

Figure 1: The connection among the copper terminations and the current leads has been realized by means of aluminium shoes, with the interpositions of indium wires on the contact surface.

This ensures that the void fraction inside the cable jacket was filled with liquid helium during current ramps and plateaux, and consequently that the whole joint remains at the stable temperature of 4.2K. This is also confirmed by the temperature readings of the 2 Cernox thermometers placed upon copper terminations. However, the analysis evidenced that the liquid helium level was not crucial for the estimation of the joint resistance in the operating conditions, and even when few centimetres of joint surface were uncovered, the measured resistance value did not change.

In the determination of the joint resistance, we disregarded those measurements in which the current plateaux were not long enough to permit to the inductive voltages arising from the current ramp to be completely discharged. We only took into consideration completely stable voltage signals. Of the two couples of voltage taps soldered by ASG on the joint, named during tests preparation Vj1 and Vj2, one (Vj1) has been disregarded after file analysis, as often showed a small but not negligible drift during long current plateaux, probably due to thermocouple voltages arising at the connector level due to temperature variations inside the cryostat.

Small variations in the measured joint resistance, up to 0.15nΩ, between measurements at different current levels, are likely to arise due to internal current redistribution in the JT60SA cable cross

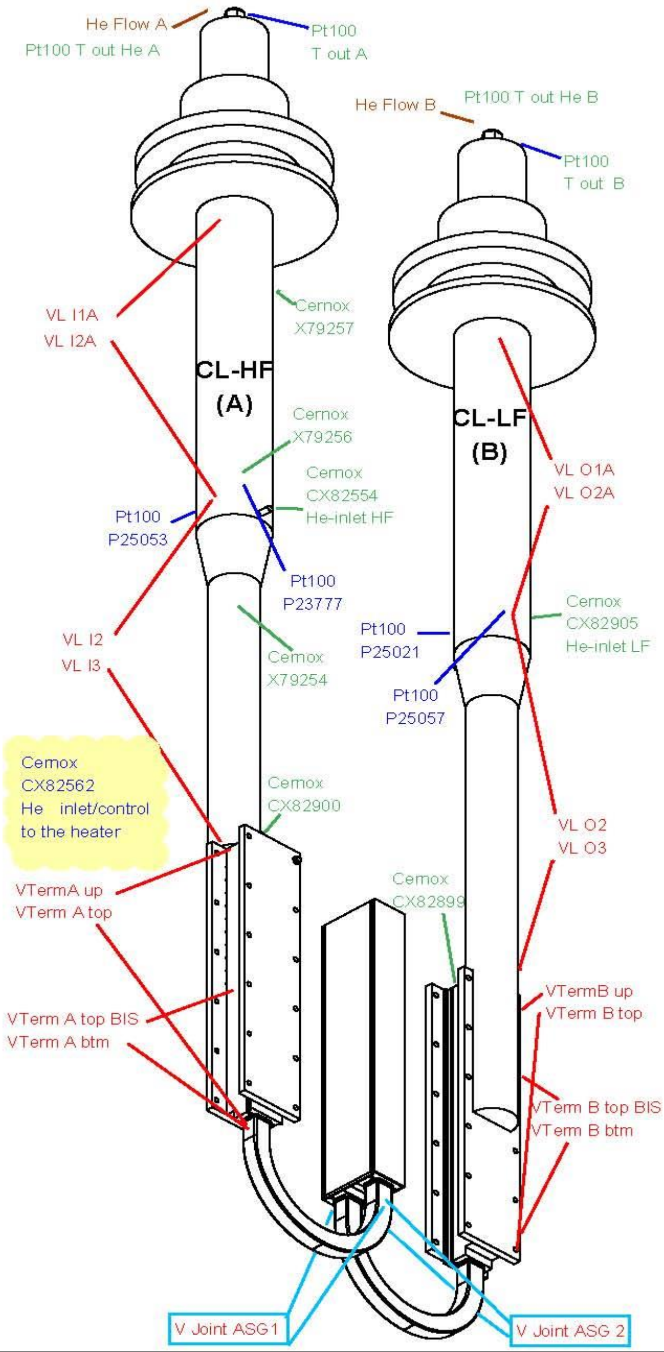

Figure 2: A sketch of JT60SA Joint and HTS current leads instrumentation during measurements.

section, which is capable of carrying higher current respect to the ones used during these measurements. The equivalent contact surface, which is up to the joint resistance, could in fact be changing, due to these current redistribution. Anyhow, these small variations are in the same order of magnitude of the measurement's error, and do not influence the results. This has been also confirmed by the fact that increasing the current ramp rate from 2000 A/s up to 15000A/s, the joint resistance variation is negligible.

For the resistance determination from the ratio between voltage and current across the joint, the corresponding offset, if present, has been subtracted from each signal during data post processing. In Figures 3-7, the ratio between the voltage measured by voltage taps Vj2 and the current across the joint is shown, together with the current itself, for several data files. The measured value of the joint resistance correspond to the value of this ratio during the current plateaux. In those measurements in which several current plateaux where performed, the resistance value was also obtained plotting the measured voltage versus current across the joint and considering the slope of the line which connects the points of minimum voltage for each current, which correspond to the compete discharge of the inductive voltage due to current ramp. In Figure 8 are evidenced, for the file 14062013_F, the part of the measured voltages that are taken into consideration in view of the determination of the minimum voltages for each current plateaux.. This kind of analysis, shown in Figures 9-12, has the benefit of being independent from offset subtraction.

Besides the joint resistance, also the resistances of the two terminations have been measured. Their values are RTA=2.5±0.15nΩ and RTB=2±0.15nΩ, where RTA and RTB correspond to the resistances of the terminations connected to the leads named lead A and lead B respectively. In Figures 13, 14, the ratio between the voltages VTA and VTB across terminations and the current are shown together with the current itself. As for the joint, the values of the terminations resistances correspond to the values of these ratios during the current plateaux. In Figures 15, 16 the slopes of the lines which connect the points of minimum voltage for each current are shown. The values of these slopes correspond to the measured termination resistances.

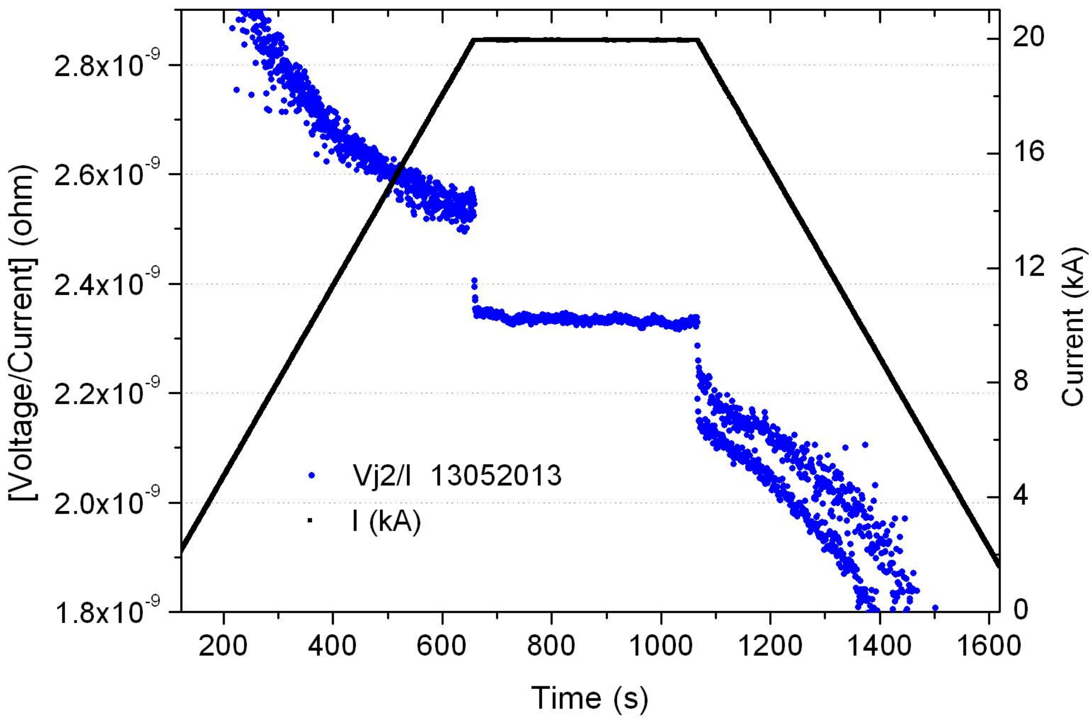

Figure 3: Ratio between the measured voltage Vj2 and the measured current across JT60SA joint and current during run 13052013 together with current.

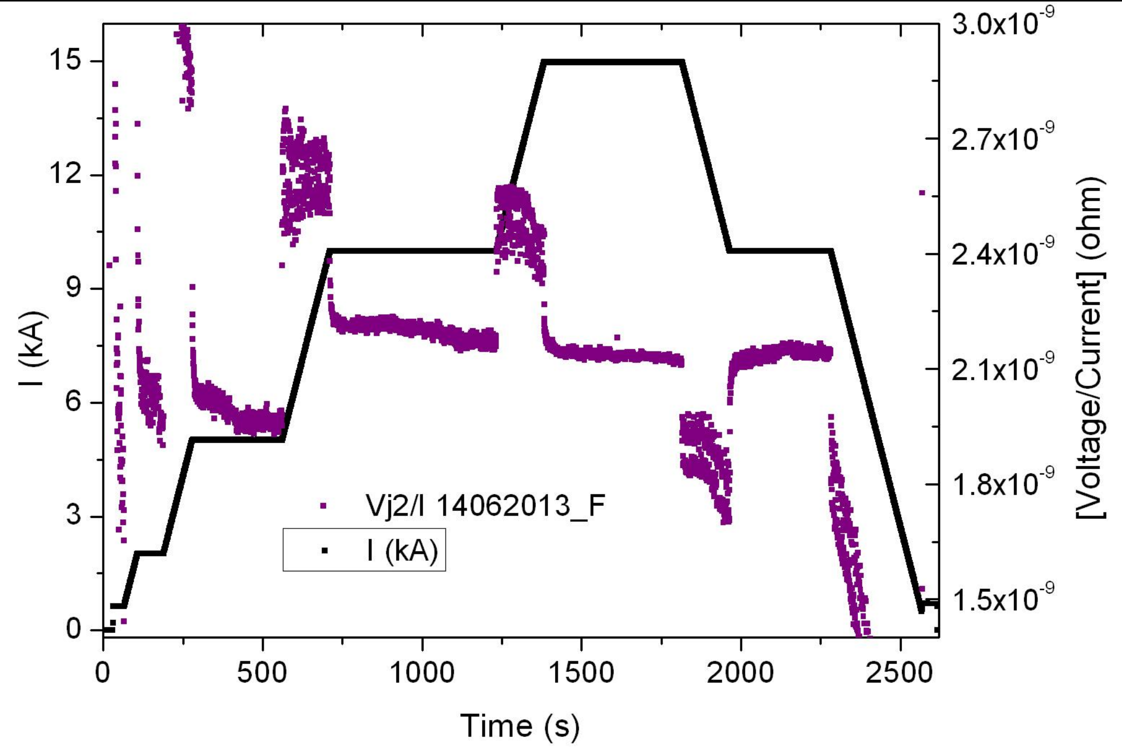

Figure 4: Ratio between the measured voltage Vj2 and the measured current across JT60SA joint and current during run 14062013_F together with current.

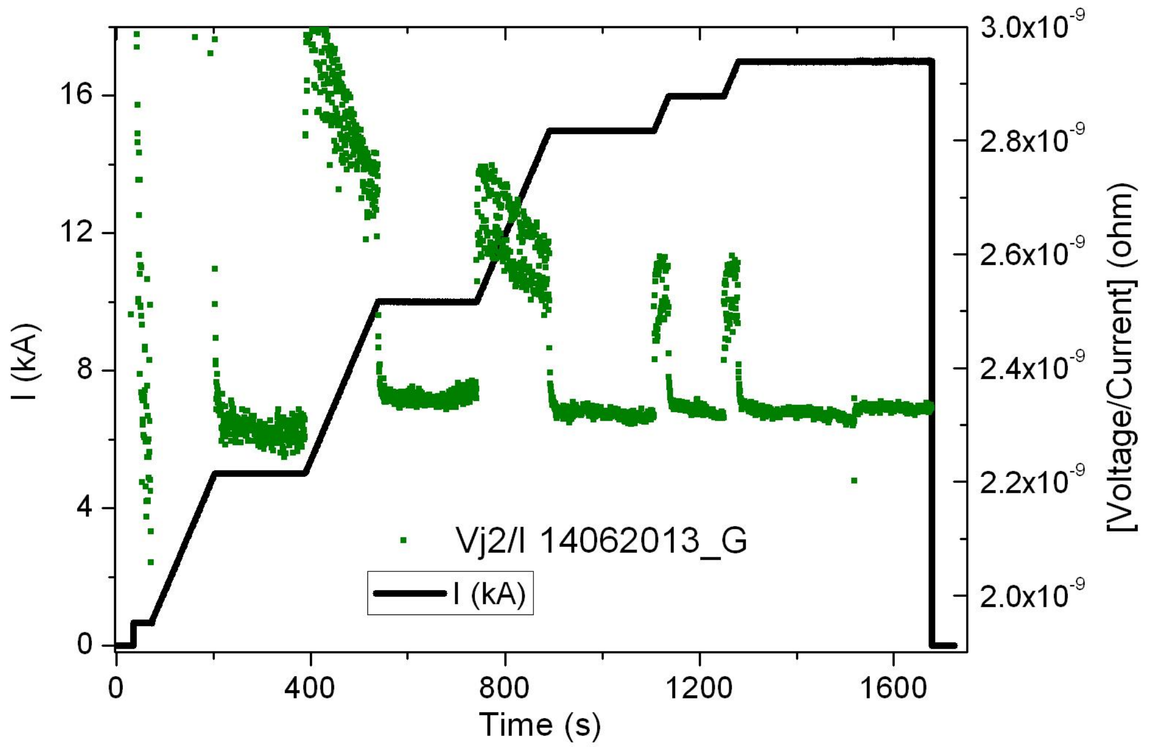

Figure 5: Ratio between the measured voltage Vj2 and the measured current across JT60SA joint and current during run 14062013_G together with current.

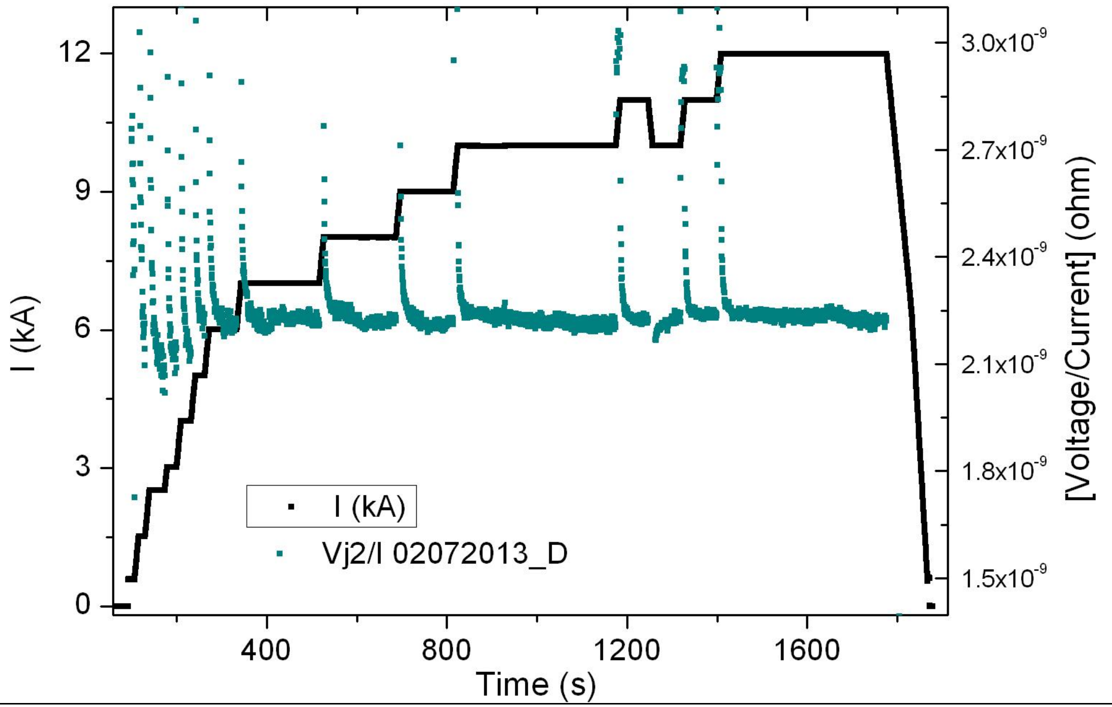

Figure 6: Ratio between the measured voltage Vj2 and the measured current across JT60SA joint and current during run 02072013_D together with current.

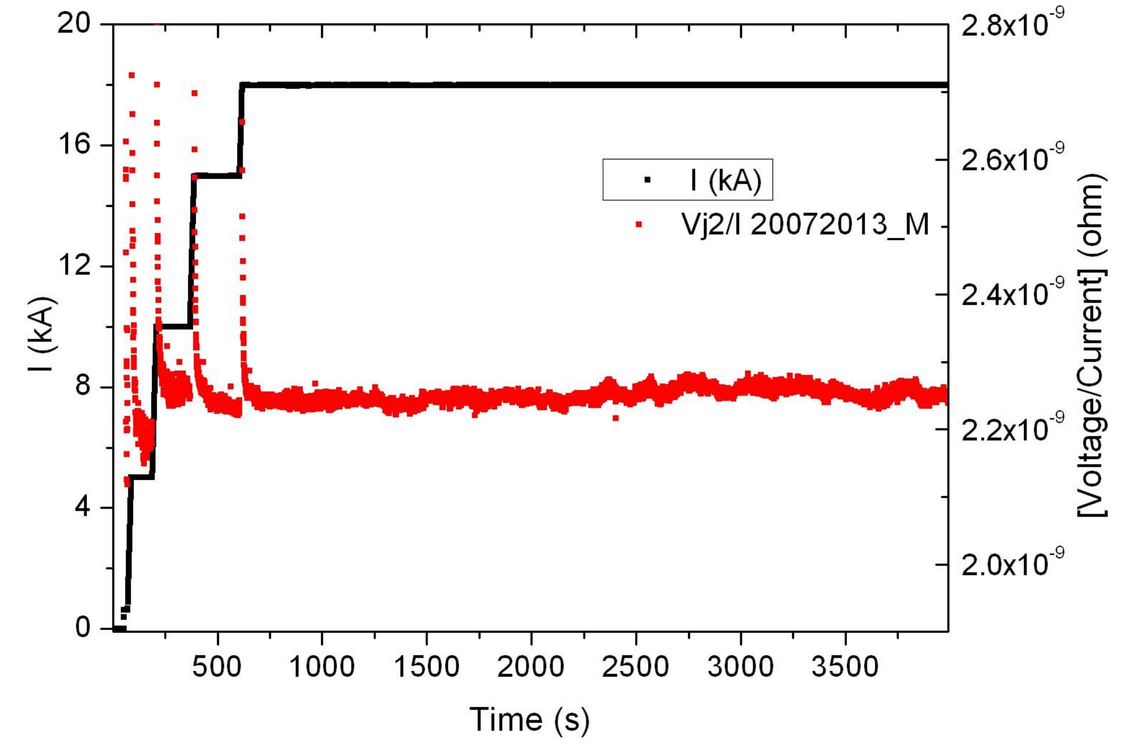

Figure 7: Ratio between the measured voltage Vj2 and the measured current across JT60SA joint and current during run 02072013_M together with current.

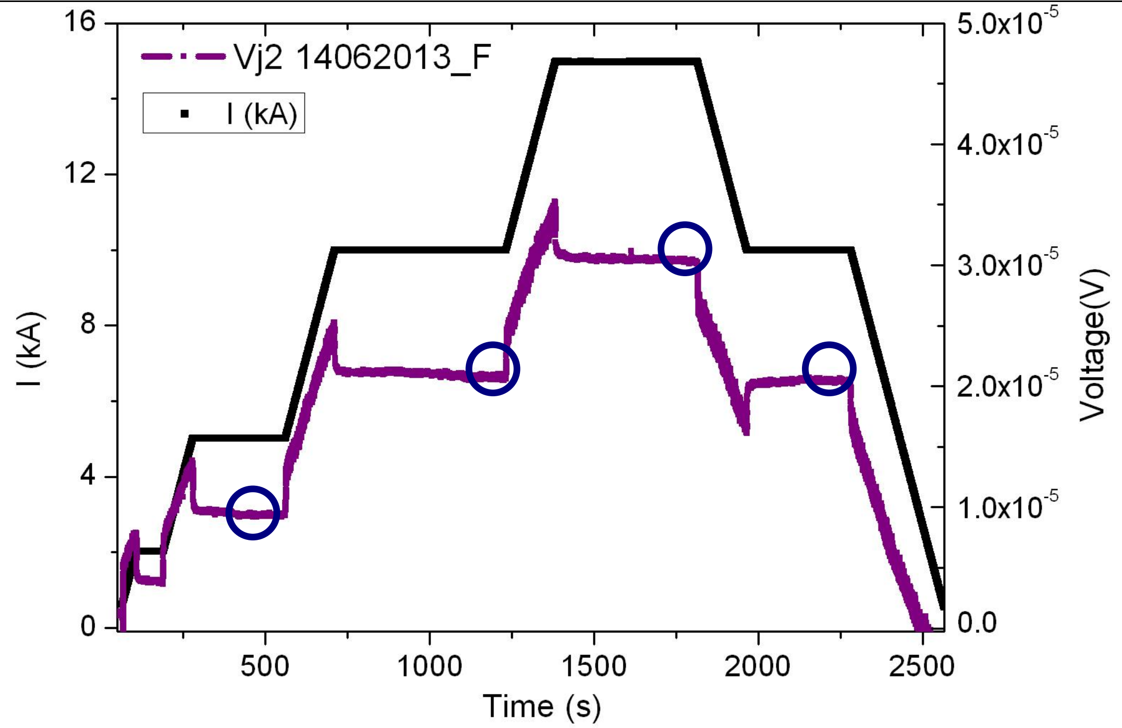

Figure 8: Measured voltage across taps Vj2 together with current across JT60SA joint during run 14062013_F. The blue circles evidence the parts of the voltage signal that correspond to the end of the current plateaux and that are used in post-processing to obtain the resistance values as the slope of the line that connects the points of minimum voltage for each current.

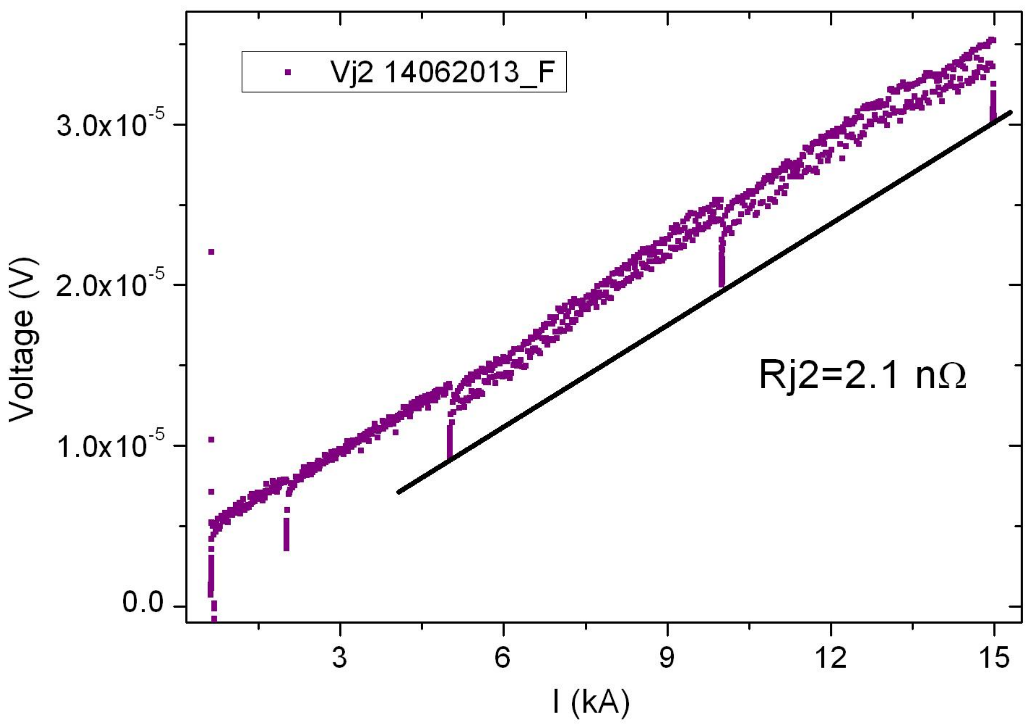

Figure 9: Measured voltage Vj2 across JT60SA joint versus current during run 16062013_F. The joint resistance value is obtained by the slope of the line that connects the points of minimum voltage for each current plateaux.

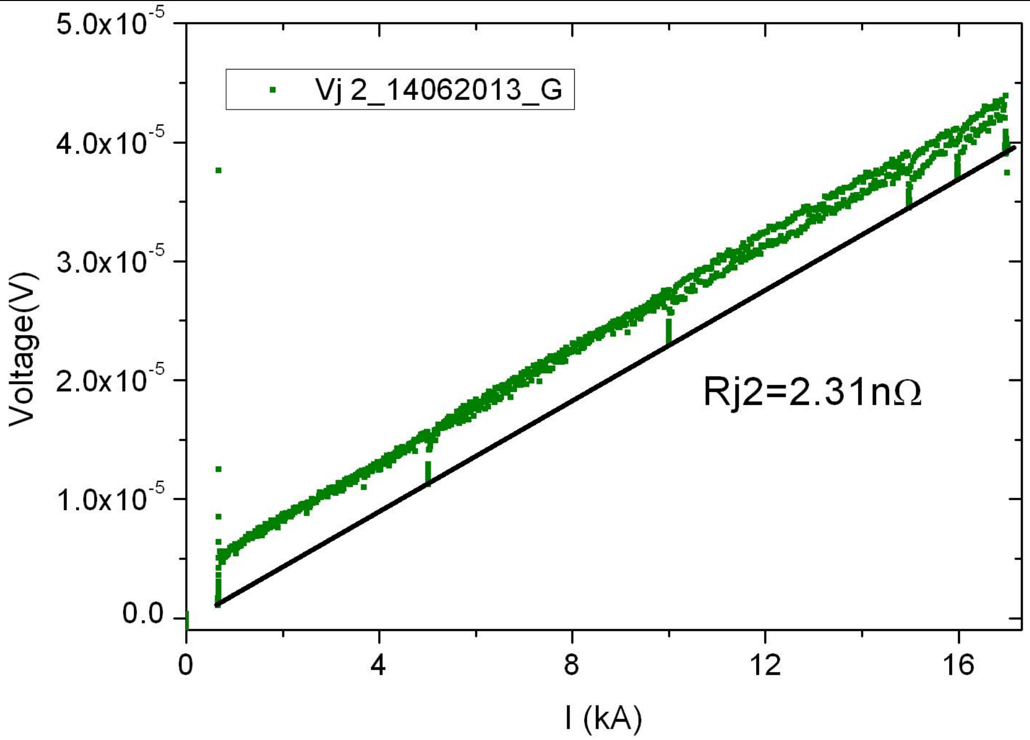

Figure 10: Measured voltage Vj2 across JT60SA joint versus current during run 14062013_G. The joint resistance value is obtained by the slope of the line that connects the points of minimum voltage for each current plateaux.

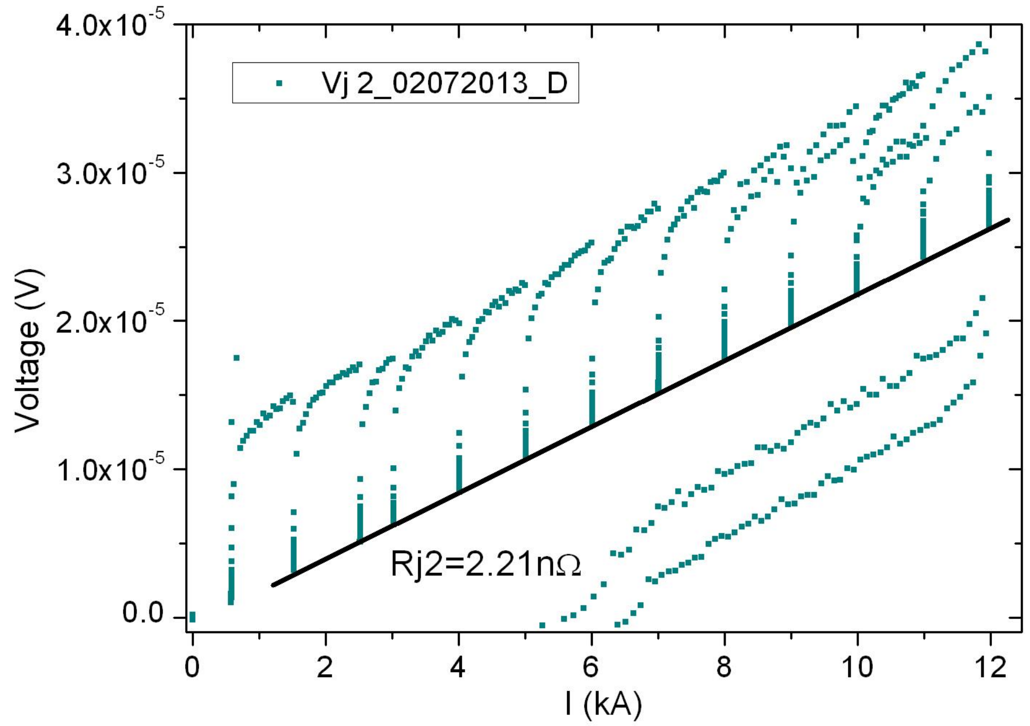

Figure 11: Measured voltage Vj2 across JT60SA joint versus current during run 02072013_D. The joint resistance value is obtained by the slope of the line that connects the points of minimum voltage for each current plateaux.

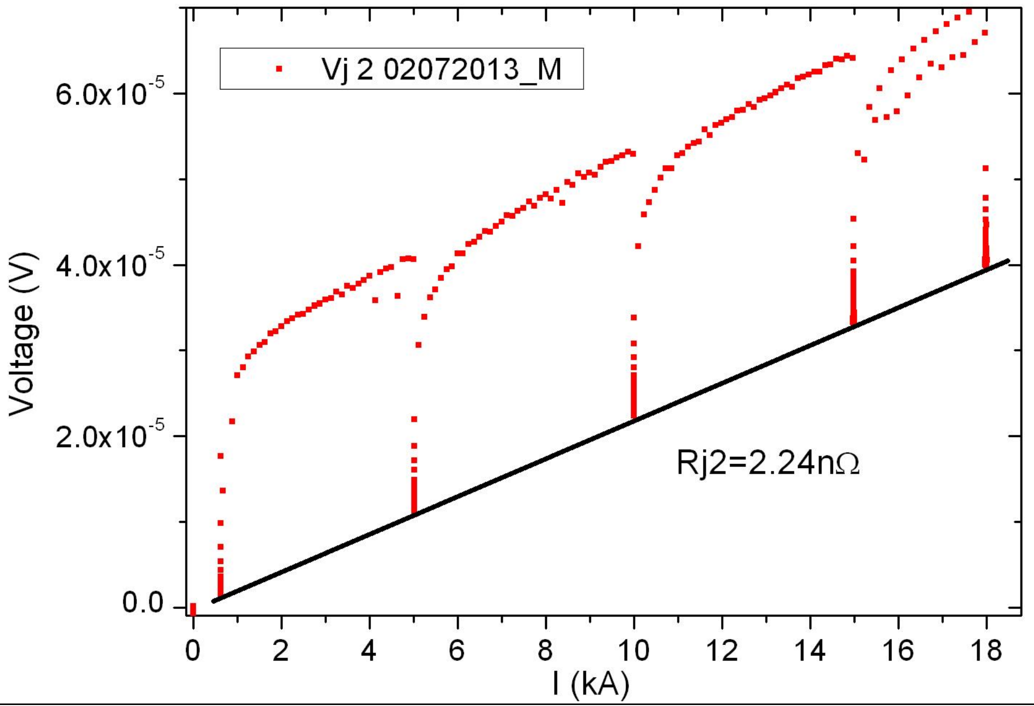

Figure 12: Measured voltage Vj2 across JT60SA joint versus current during run 02072013_M. The joint resistance value is obtained by the slope of the line that connects the points of minimum voltage for each current plateaux.

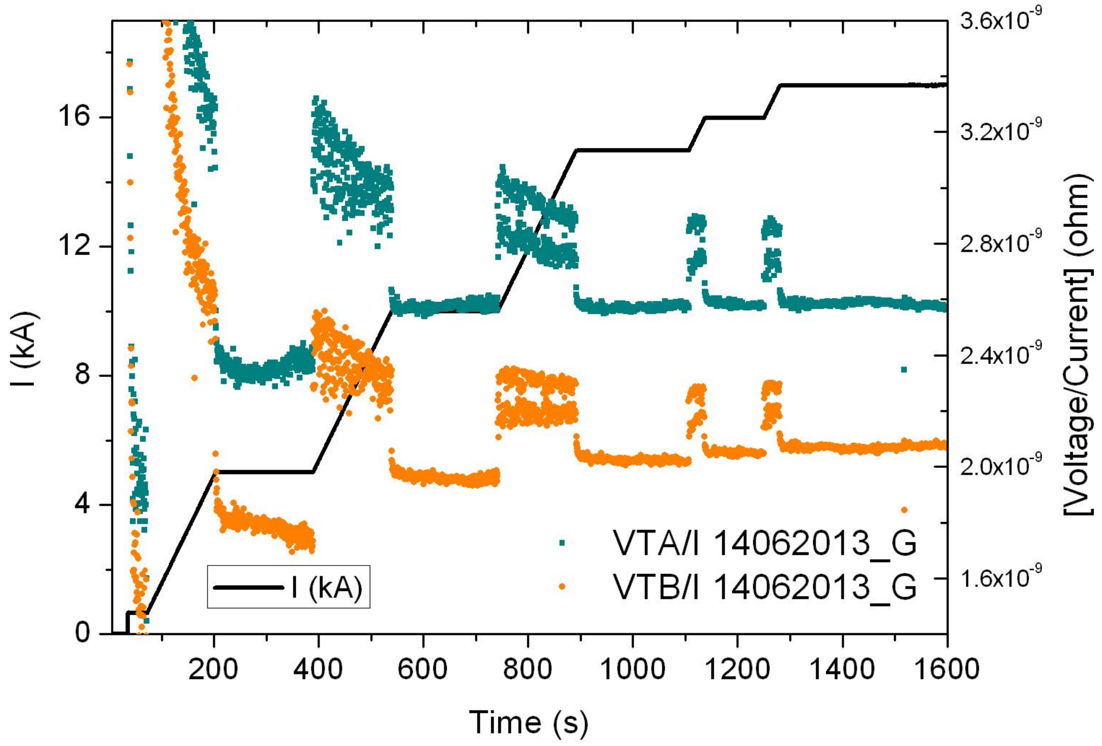

Figure 13: Ratio between the measured voltages VTA and VTB and the measured current across JT60SA joint together with current during run 14062013_G.

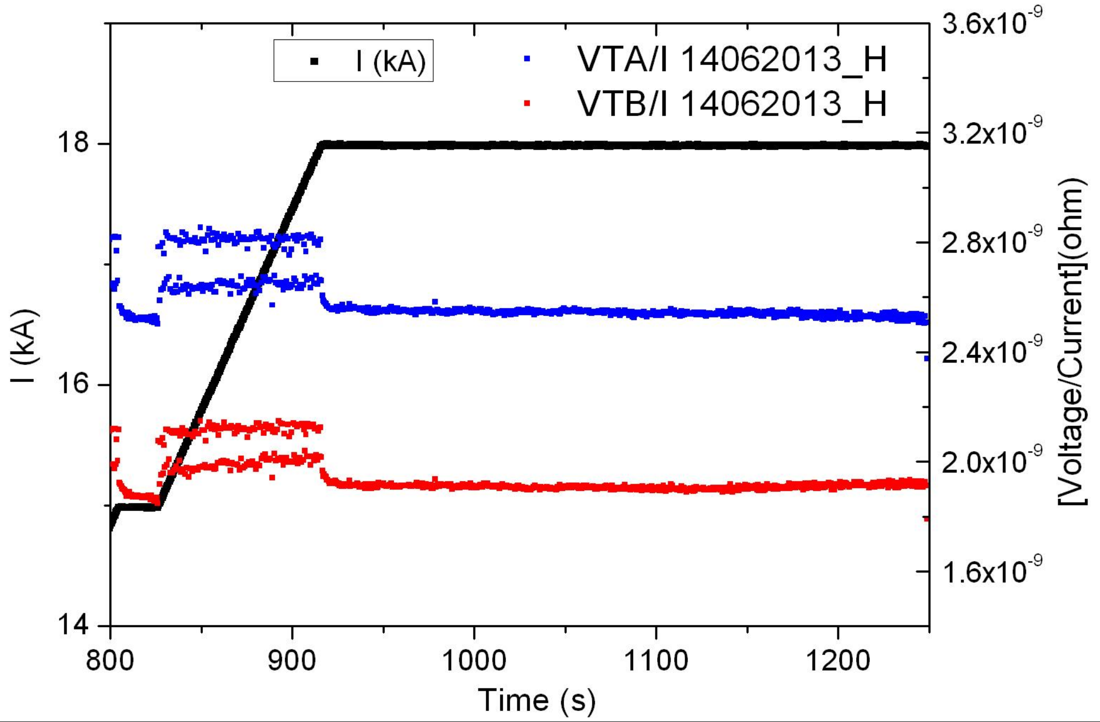

Figure 14: Ratio between the measured voltages VTA and VTB and the measured current across JT60SA joint together with current during run 14062013_H.

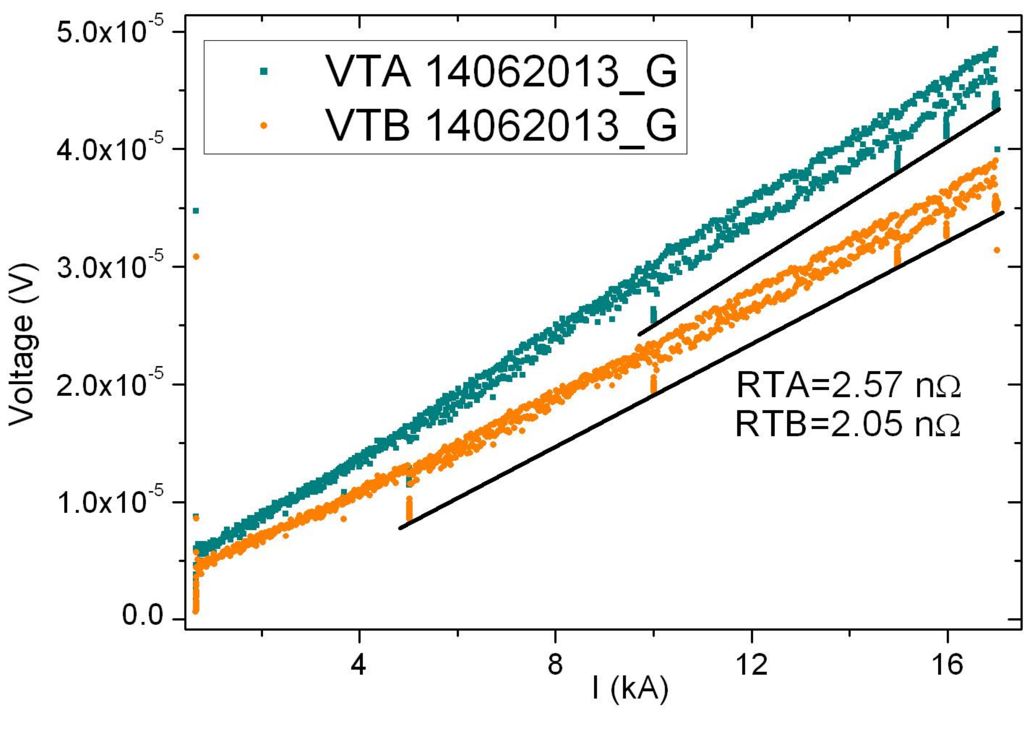

Figure 15: Measured voltages VTA and VTB across JT60SA joint versus current during run 14062013_G. The terminations resistances values are obtained by the slope of the lines that connect the points of minimum voltage for each current plateaux.

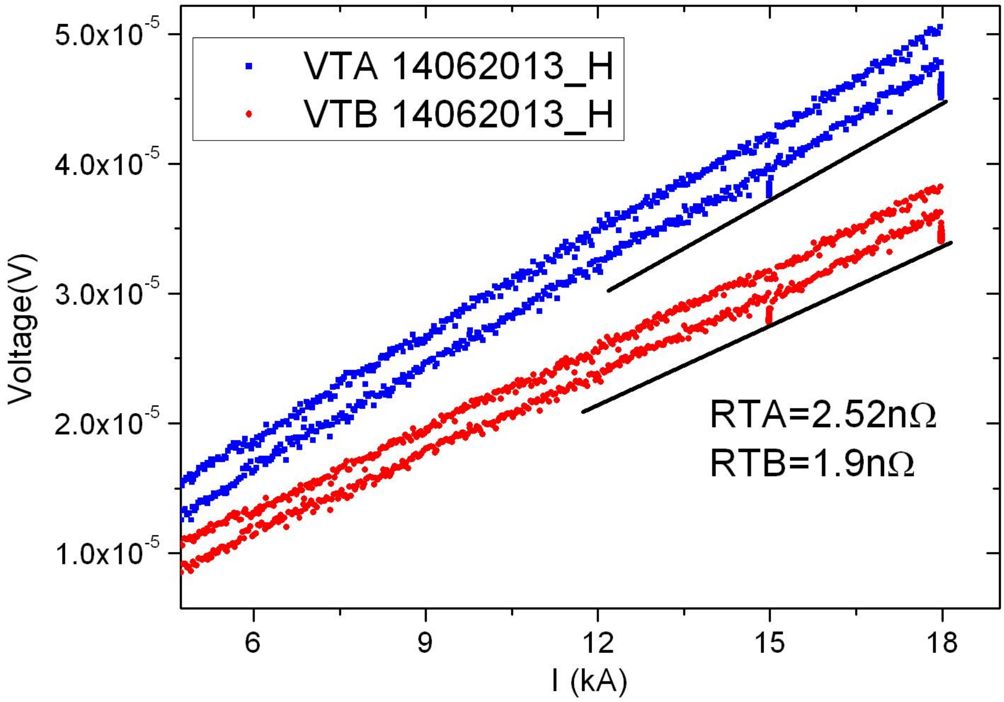

Figure 16: Measured voltages VTA and VTB across JT60SA joint versus current during run 14062013_H. The terminations resistances values are obtained by the slope of the lines that connect the points of minimum voltage for each current plateaux.

Conclusions

The measurement and the post-processing applied to the data give the result that the JT60SA joint resistance is 2.25±0.15nΩ.