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Demountable Coaxial Clamped Joint For ITER Central Solenoid Module Final Test Program

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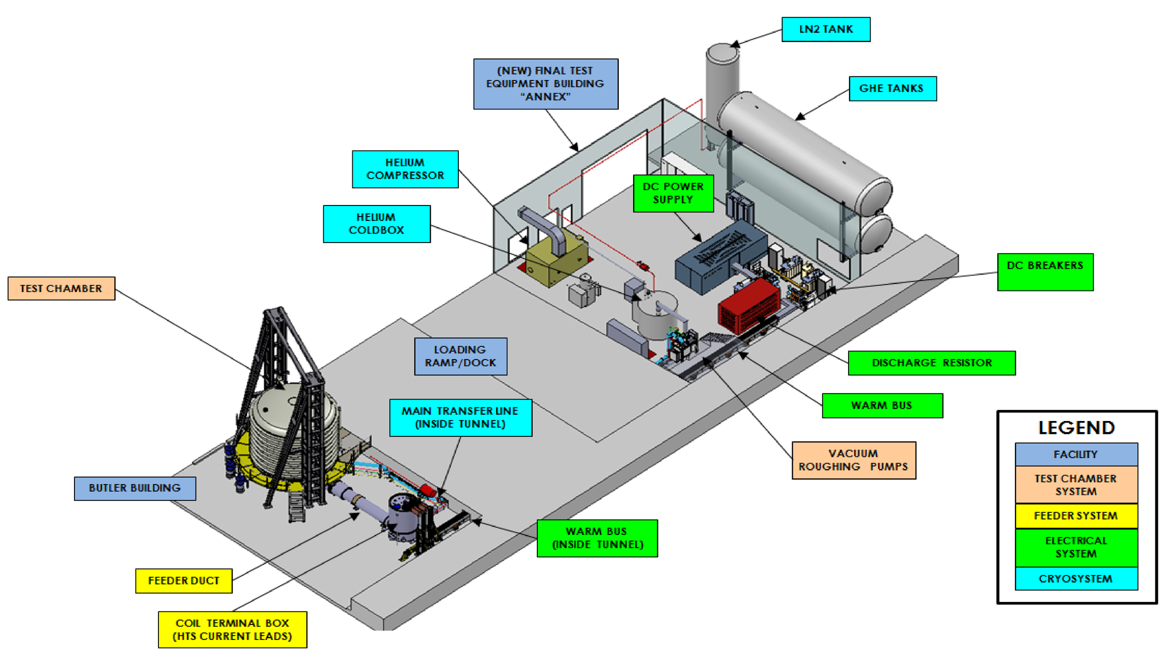
GENERAL ATOMICS

Abstract:

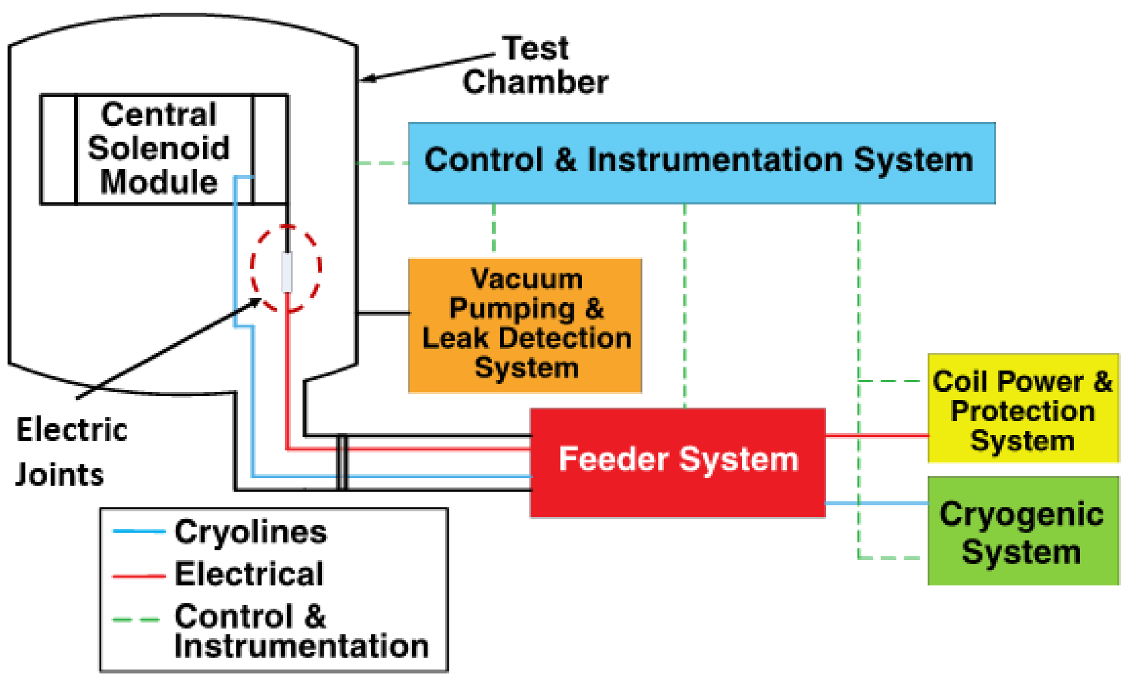
The ITER Central Solenoid Modules (CSM) are being fabricated at General Atomics (GA) at their Magnet Technologies Center in Poway, CA. Each of the seven modules will undergo final testing at the GA facility to demonstrate their performance at 48.5 kA, 11 T, and at 4.5 K. In order to perform tests on multiple modules, a demountable coaxial joint using indium wires was developed to connect the modules to the feeders. Two full scale joints were fabricated to establish the assembly technique and preliminarily tested (up to 3 kA) on the CSM qualification coil (Cu conductor). The same joint components were then tested using a superconducting jumper (NbTi) and their resistance measured (2.3 and 4.9 nΩ, at 4.5 K, 40 kA). In parallel to measuring the voltage across the joints, a calorimetric evaluation was also performed and it confirmed the low resistance measurements of both joints. Testing of the same coaxial clamped joints on a heat treated Nb_3Sn jumper took place in February 2019 and the results are reported in this paper. With these acceptable results, the same joint components and assembly techniques will be utilized to connect the 14 joints on the seven CSM (Nb3Sn) for full current testing. This work was supported by UT-Battelle/Oak Ridge National Laboratory under sponsorship of the US Department of Energy Office of Science under Awards 4000103039 and DE-AC05-00OR22725.

Introduction

Following completion of fabrication, each of the seven ITER CSM will undergo testing at room temperature, followed by a series of tests at 4.5 K. The GA 4K final test facility equipment layout is shown below.

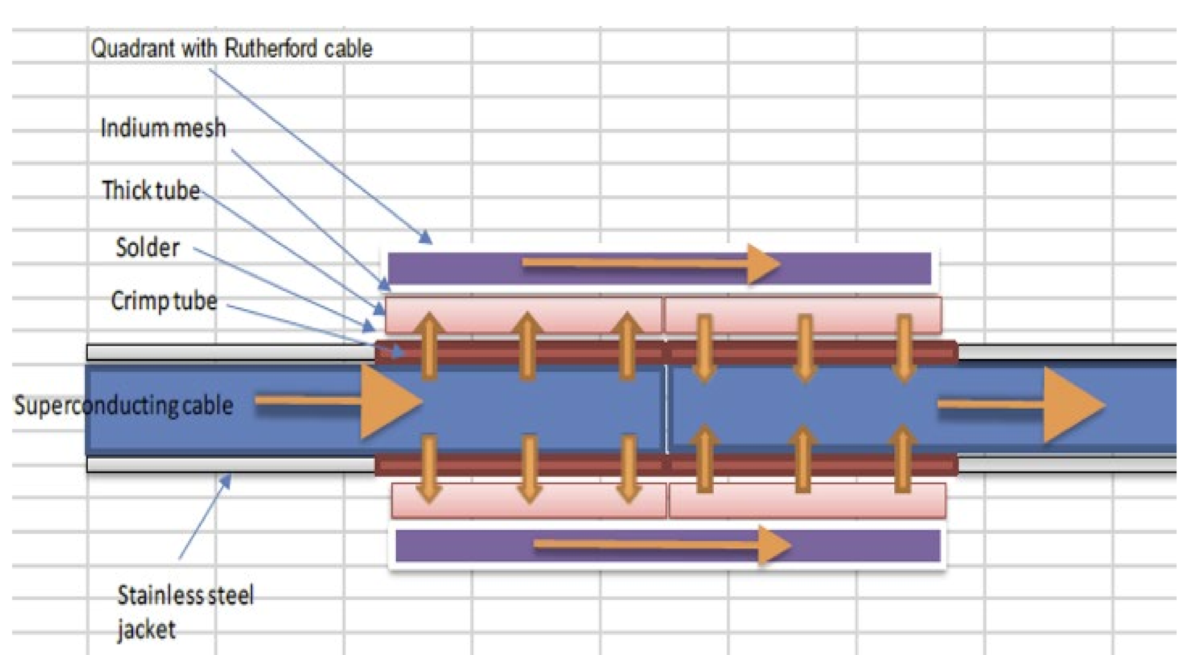


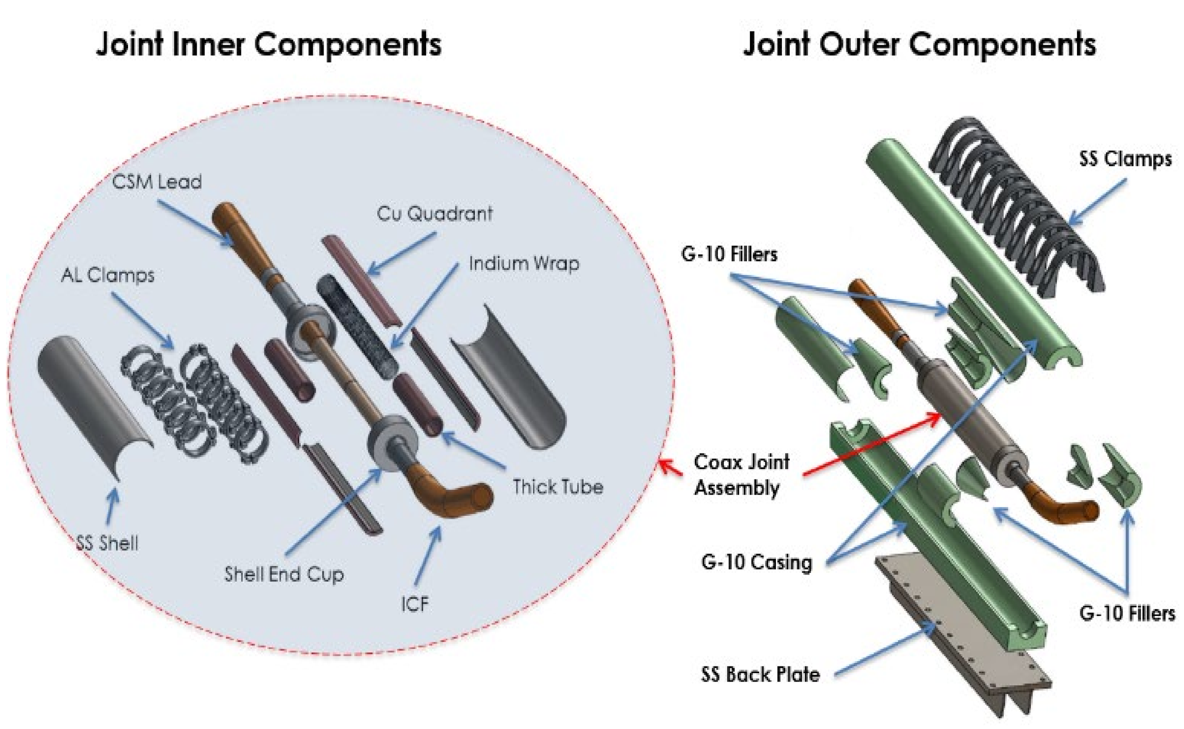
Each superconducting (Nb3Sn) coil has terminals to connect to the superconducting (NbTi) busbar of the feeder system. The block diagram of the CSM supplies, and location of the electric Demountable Coaxial Clamped Joints are shown below.



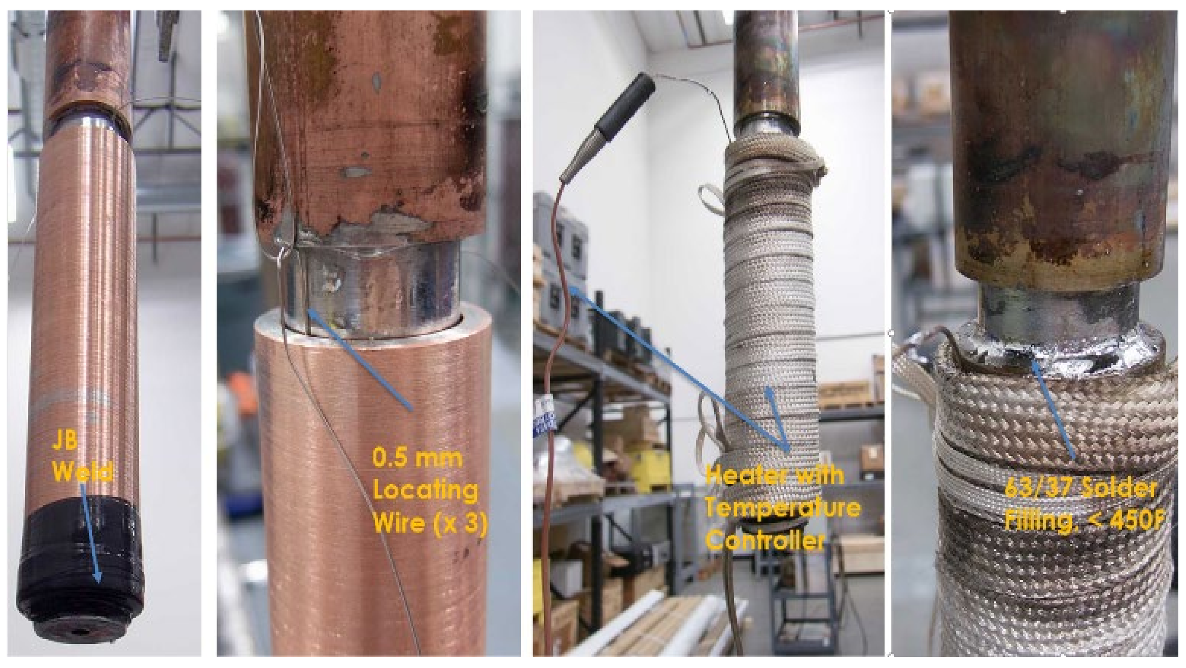
Study, Design, and Methods

Based on GA development, and past experience with the CS Model Coil, 1.27 mm diameter 99.99% pure indium wire, and the LHC type 2 Rutherford cable, was selected for providing a low resistance current element between the feeder and the CSM. The electrical schematic, the current pattern, and joint internal and outer components are shown in Figures below.

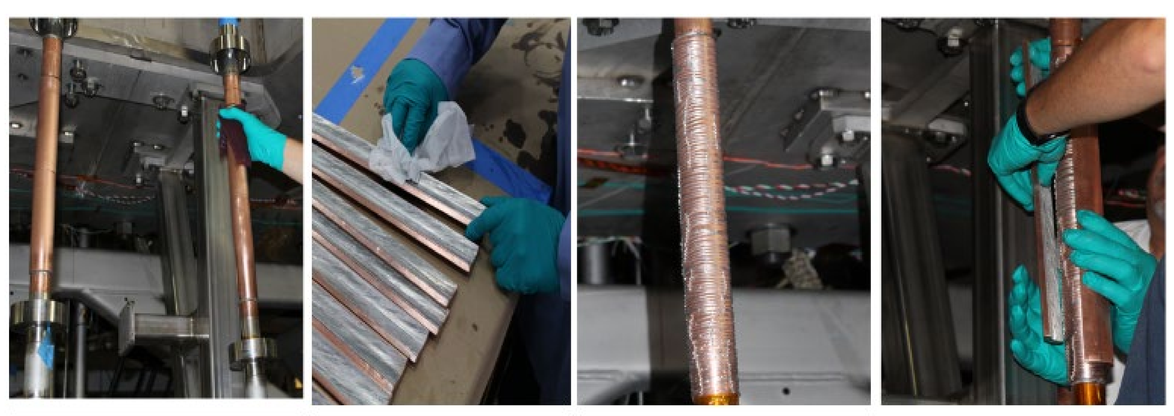




The heat treated Nb3Sn conductor in the CSM terminals is enclosed inside a 1 mm wall copper tube that may not be adequate to prevent overstrain of the strands (<0.1% limit). Adequate compressive force is needed to compress the indium wire at the electrical interface to create stable interface pressure through the operational life of the joint. In order to prevent overstrain of the terminal reacted Nb3Sn strands which are enclosed in the 1 mm thick copper tube, a maximum joint interface pressure of 15 MPa was adopted. To prevent overstraining of the CSM conductor under compression, a 4mm thick tube was soldered outside of the 1mm wall tube. Pictures below show the soldering technique.



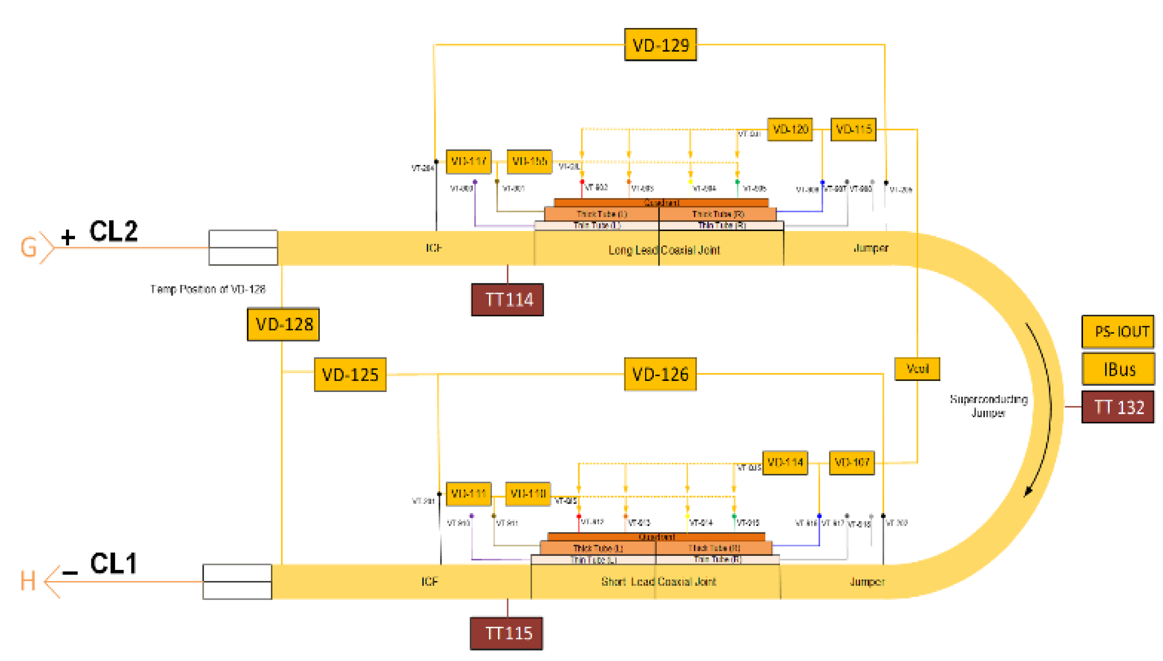
The joint assembly steps are shown in Pictures below. To achieve both high pressure and large deformation of the indium wire, high strength stainless steel clamps were used with torques up to 11.3 N-m (23 MPa pressure). This torque is applied and the joint re-torqued multiple times over 24 hours. These clamps are then replaced with custom aluminum clamps torqued to 7.3 N-m (15 MPa) to provide the proper preload at 4.5K due to the differential thermal contraction. A helium containment can is then welded over the joint.



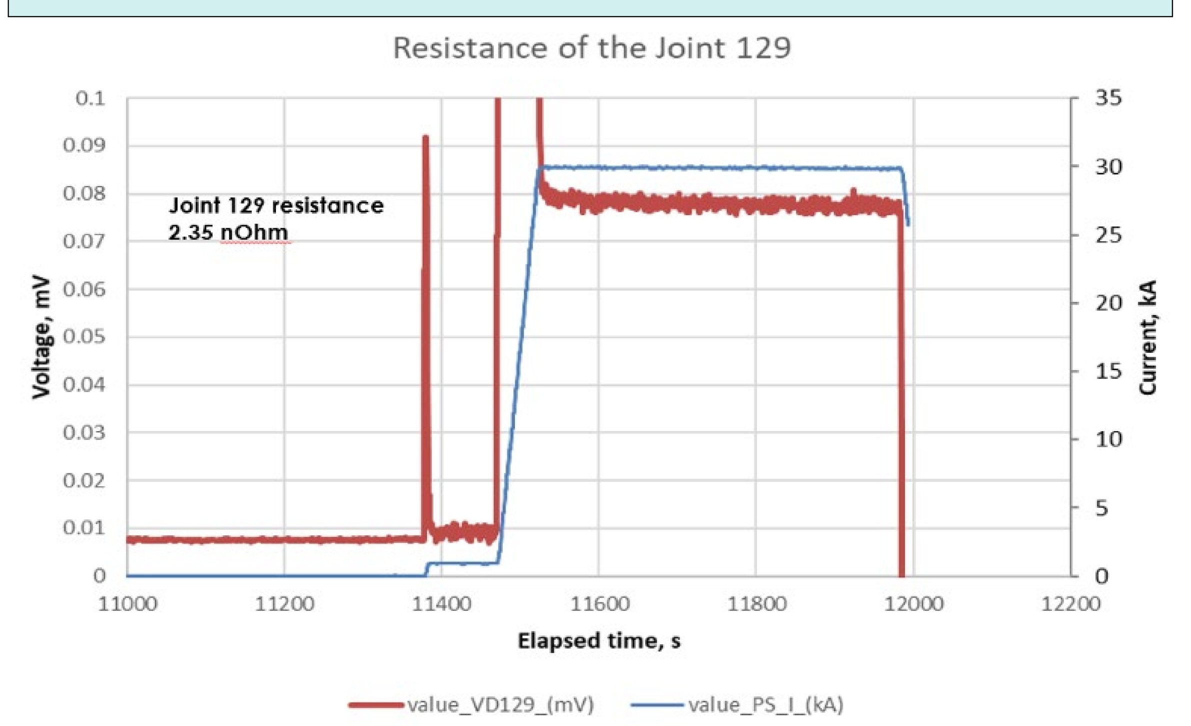
Coaxial clamped joint ends with soldered Cu tubes aligned/cleaned	Cu quadrants with soldered Rutherford cable, cleaned	Mockup and Busbar Cu tubes wrapped with Indium wire	Four NbTi quadrants fitted over Indium wire

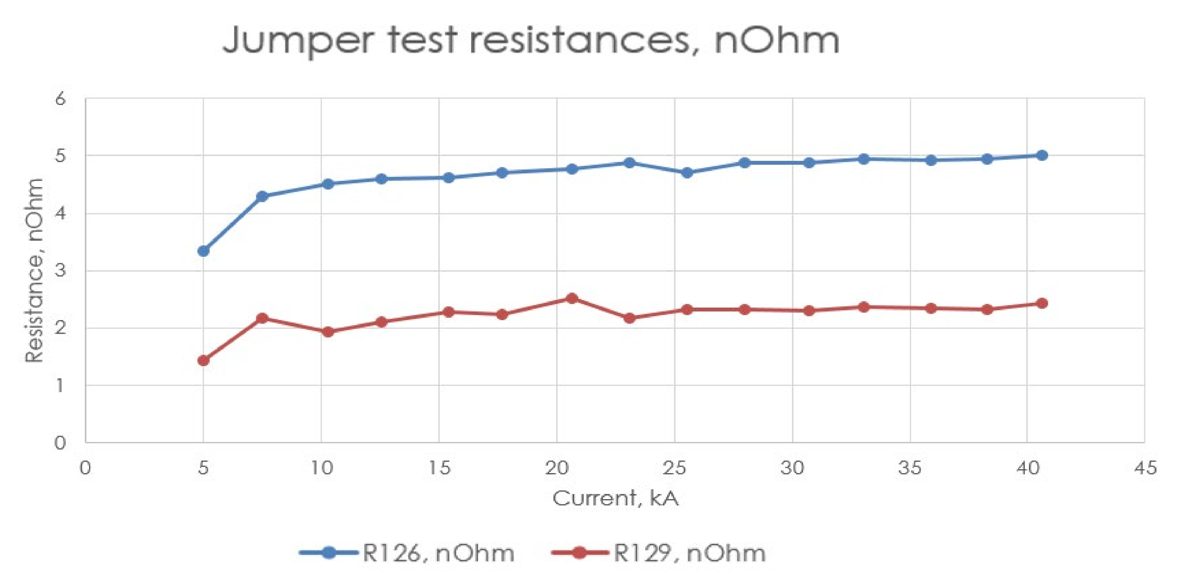
Indium compression clamps installed	Vacuum can welded	Electrical Insulation applied	Structural support clamps installed

The first high current electrical testing at 4.5K was performed on the NbTi superconducting jumper test. To measure the overall resistance and each component of the coaxial joint current path, voltage taps were installed on each of the joint components as shown in schematic below.



Data Collected



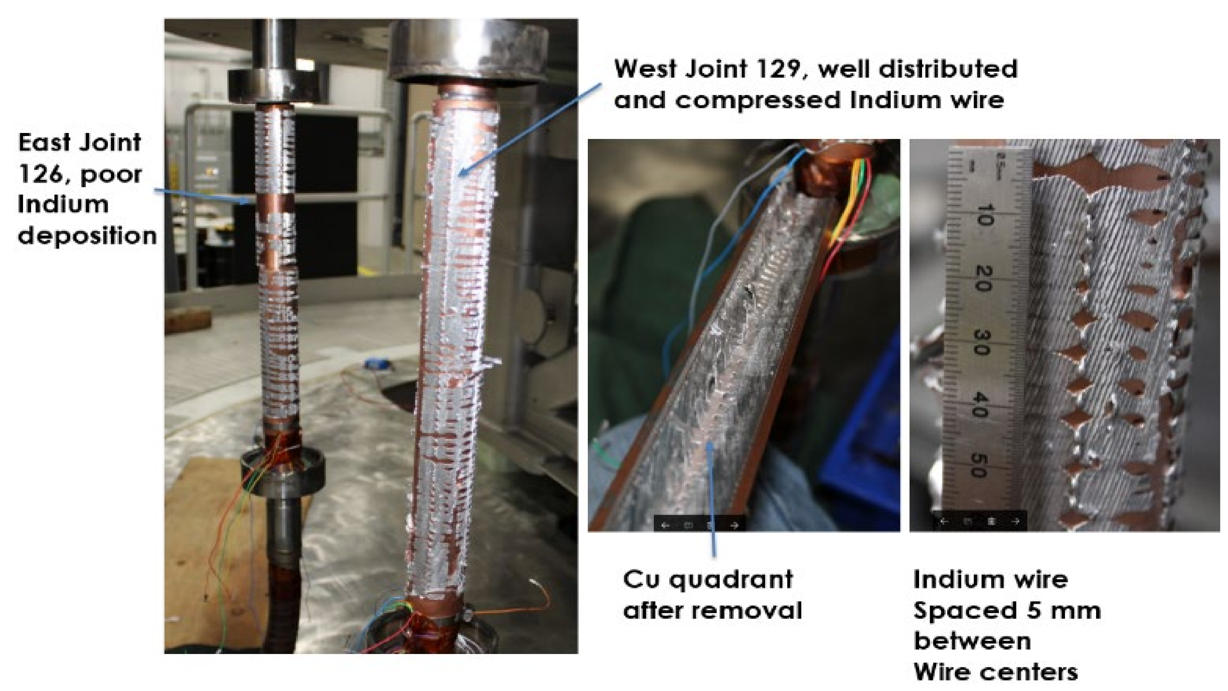


Coaxial Clamped Joint, Electrical Resistance, Function of Current

To confirm the electrical measurements, we also performed calorimetry measurements. The calorimetry is performed by measuring the incoming and outgoing helium enthalpy and the mass flow. The calorimetry shown that the results a reasonable.

Post Testing Examination

The post testing evaluation of the coaxial joint indium interface showed good indium deposition and flow joint R129, and relatively poor indium deposition in joint R126, which could explain the higher resistance at that joint interface. Pictures below shows the disassembled components of both joints.



Conclusion

The Demountable Coaxial Clamped Joint design, proposed and developed at GA, has been demonstrated for testing the CSM and other high DC current magnets. Multiple test articles have been installed and tested at the GA test facility. Use of the individual voltage taps at each interface of the joint allows for easy determination of the higher resistance components, and allowing for quick utilization of the corrective action. Most of the joint components are reusable - which allows for future cost reduction for multiple joints test evaluation programs.

Status

The consistent performance, low resistance, and test data collected to date on the GA Demountable Coaxial Clamped Joints, have already provided a valuable basis for the design and testing of the ITER CSM to the lead extension joints. Currently, the joints are being used in ongoing testing of the CSM joint qualification at GA. To date, fourteen Demountable Coaxial Clamped Joints have been tested at the GA test facility. In all cases, if cable-crimping tube resistance is low, the squeezed Indium wires interface gave acceptably low resistance.