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Welding of Niobium to Stainless

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The present concept of the TESLA accelerator involves superconducting cavities made of pure Niobium cooled by superfluid Helium contained in stainless steel cryostats. The design of these components can be simplified if the welding of pure Niobium to stainless steel can be made in a straightforward manner. There is mention in the literature[1] that welds of Niobium to structural materials like steel are brittle. We report here our experience with a testing piece containing two such welds. It was made in preparation for the design of a testing facility for side-couplers. Side-couplers are semi-rigid coaxial elements that conduct the 1.3 GHz RF power from room temperature to the superconducting cavities at 1.9 K. The weld tests showed at first very encouraging results, but later, when inadvertently submitted to tension the main weld cracked. Nevertheless, we find the material this technical note relevant since such welds when designed into low tension situations have a good chance of performing.

The weld in question joins a Niobium tube passing through a hole in a stainless steel plate to this plate in a superfluid leak-tight seal. The tube has an outside diameter of 76.2 mm and a 1.59 mm thick wall. The plate is 4.76 mm thick and made out of type 304 stainless. Figure 1 is a drawing of the test-piece incorporating one such weld among others and allowing us to check for vacuum leaks at cryogenic temperatures

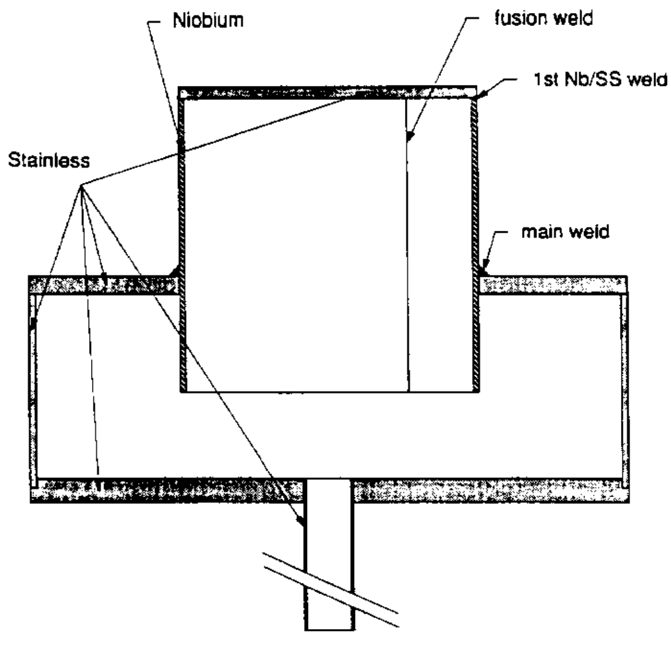

Figure 1. Test-piece for Niobium-Stainless welds

We proceed now to describe the manufacture of this test-piece. The Niobium tube was manufactured by roll forming a well characterized[2] Niobium sheet into a tube, and fusing the edges which were flat (i.e. not completely rolled). The high melting temperature of Niobium (3114 K) and its easy oxidation above 672 K required this operation and all welding involving Niobium to be done in a Helium filled glove box. Upon re-rolling of the tube after fusion-welding to remove the flat spot, this fusion-weld cracked. It was then redone and the flat distortion left on to be compensated by appropriate customizing of the hole in the stainless plate. The next weld, of the Niobium tube to the type 304 stainless disk cap was done using a type 309 stainless filler rod, which had shown some promise in a preliminary tack weld try. Inspection of this weld revealed several transversal cracks. It was then re-welded using a filler rod of Tig-Tectic 680[3]. The weld turned out bulky but vacuum tight. The main weld was then done using the latter filling rod, again in the Helium atmosphere of a glove box. It should be pointed out that the melting temperature range of type 304 stainless steel is 1670-1720 K, far below the Niobium melting point but considerably above its oxidation temperature. After the other stainless to stainless welds were made the test-piece was vacuum checked at room temperature (300 K) and at 78 K.

The low temperature vacuum check was carried out using a Mylar bag around the test-piece, filling it with Helium gas through a Teflon tube and dipping the test-piece so wrapped into liquid Nitrogen, all this while its inner volume was connected to a vacuum pump through a mass spectrometer type leak detector. This operation was repeated three times with warm ups to room temperature in between. There was no sign of a leak. The sensitivity of the leak detector used is 4.0×10^{-10} atm.cm^3/s. Since most of the differential contraction between the materials involved between 300 K and 1.9 K already takes place by 78 K this test was considered adequate, and our experience give us confidence that the seals are superfluid leak tight. This confidence is further based on the expansion coefficients[4] involved: stainless contracts 0.296% while Niobium contracts 0.143% over the 300-4 K temperature range and the weld design places the stainless around the Niobium.

One extra care should be taken in welding Niobium for TESLA: Niobium, when heated above 672 K, readily absorbs Oxygen and its purity, essential in these superconducting cavities, will get compromised. So the parts should be left to cool completely in the Helium atmosphere of the glove box. Also, eliminating residual Oxygen in the glove box (by evacuating the glove box prior to admitting Helium) would contribute to satisfy this concern. The welding gas used in these TIG (Tungsten Inert Gas) welds was Argon.

The inadvertent creation of an external vacuum to the test piece during a later leak testing operation placed the main weld in tension and caused it to crack. It should be pointed out that these welds are somewhat magnetic and we have not checked the superconducting and thermal conducting properties of the Niobium tube as processed.

We thank Mark Ruschman and Frank E. Juravic for the leak tests involved in this project.

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[1]R. Terrence Webster, Metals Handbook 9th Edition,vol. 6,Welding Brazing and Soldering p.459, American Society for Metals (1983)

[2]Produced and characterized by Teledyne Wah Chang Albany, P.O. Box 460, Albany, Oregon 97321, tel. (503)926-4211.

[3]Manufactured by Eutectic Corporation, 40-40 172nd Street, Flushing, NY, 11358-9981, tel. (718)358-4000.

[4]R.J. Corruccini and J.J. Gniewek, "Thermal Expansion of Technical Solids at Low Temperatures", National Bureau of Standards Monograph 29 (1961).