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OPTIMIZATION OF ILC CRYOMODULE DESIGN USING EXPLOSION WELDING TECHNOLOGY

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Abstract

In the current ILC TDR design both the helium vessel shell and the connected pipes are made of expensive titanium (Ti), one of the few metals that can be welded to niobium (Nb) by the electron beam technique (EBW).

We describe work done by JINR/INFN collaboration on the construction and evaluation of transition elements, obtained by explosion welding, which could couple the niobium cavity to a stainless steel (SS) helium vessel. Several designs for these transitions have been produced and studied showing varying levels of reliability.

Based on this experience a new design, including a minimal titanium intermediate layer, has been built. Tests of resistance of the bond to extreme temperature shocks like EBW and exposure to cryogenic temperature are presented.

INTRODUCTION

Initial work on this subject was the development of a bimetallic transition element Ti+SS from the He-supply pipe to the He-vessel to be able to build this pipe and all other ancillary parts connect to it in SS (see Fig.1).

Explosion welding of two different metals is a well-known technique, but it is normally used only to weld flat surfaces, making the construction of cylindrical transitions rather cumbersome.

A key development was obtained in collaboration with the Russian Federal Nuclear Center Institute of Experimental Physics (RFNC-VNIIEF in Sarov) where a unique method for welding coaxial tubes [1] was demonstrated: two coaxial tubes of the same diameter and thickness, with an internal removable steel core, were connected by means of an external explosion around a SS collar (see Fig.2).

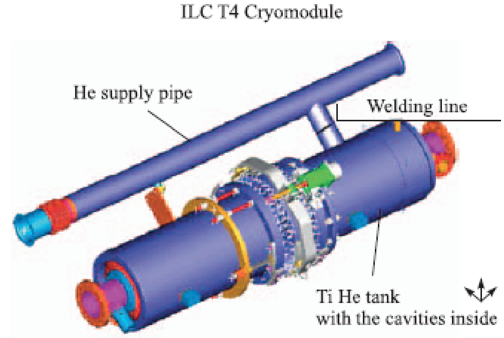

Figure 1: He-vessel connect to He-supply pipe.

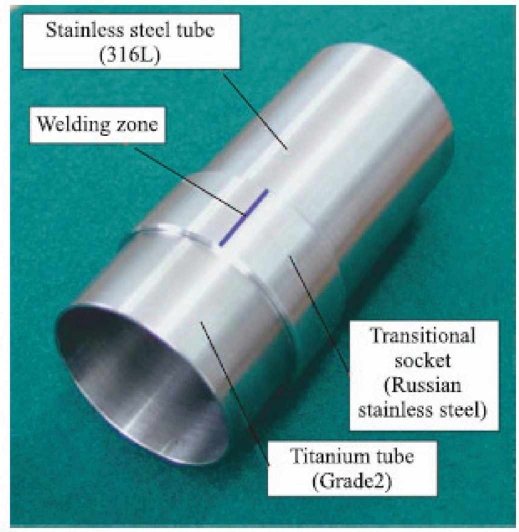

Figure 2: Ti+SS transition element.

Several samples were produced with this technique using various materials and dimensions. Finally ten samples matching the ILC cryomodule design were built and tested. The Ti+SS samples were subjected to a primary metallographic investigations of the welded joint including: macroanalysis, microanalysis, and measurement of microhardness [1]. The shear strength of the welded joint was also measured [1], the result turned out to be quite impressive: τ_{sh} about 250 MPa.

These samples were carefully leak-checked after several thermal cycles between room and liquid nitrogen temperature (77 K); no leaks were found [2,3,4,5]. They were also filled with helium at 6.5 atm and cooled to about 6 K in a cryo-cooler. The resistance of the joint after TIG welding close to it was also tested [6].

Finally the Ti+SS transitions were tested at Fermilab at the 2K temperature and under real Cryomodule conditions in the Fermilab's Horizontal Test System (HTS) and the A0 Vertical Test Dewar (A0VTD). No leaks were found also in this case [7,8,9,10].

The success obtained in explosion welding of bimetallic Ti+SS tubes led the collaboration to try a similar technique directly on Nb+SS tubes. This would allow the construction of a SS helium vessel using this transition element to connect to the cavity.

This new design would considerably facilitate the construction of the Cryomodule and, most of all, would substantially reduce the total cost of the accelerator.

Two schemes of making a transition element between the niobium cavity and the steel shell were studied: in the first the niobium tube is welded directly to the SS flange

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from inside by internal explosion in the tube; in the second a SS collar is welded to the Nb tube by external explosion and then the SS flange is welded to it. The fabrication of Nb+SS transition elements by internal explosion appears to be preferable because it is a simpler and cheaper process.

Four Nb+SS transition samples, two for each of the two options, were made and tested in Sarov, Pisa and Fermilab; Figure 3 shows one of them made by the internal explosion.

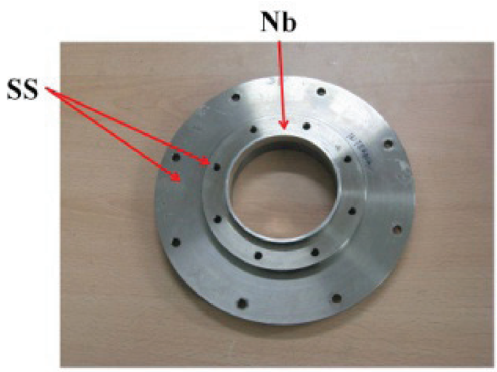

Figure 3: Nb+SS sample.

The first leak tests under extreme conditions of thermal cycling with liquid nitrogen and ultrasonic exposure gave us good results.

Some problem however developed in the first sample tested after welding Nb rings to both sides of the tube by EBW at the Sciaky Company (Chicago). It was thus demonstrated that of high residual stresses induced by superposition of the explosion bonding process and temperature loading greatly affected the joint produced by explosion welding – plastic deformation and destroy of weld seam.

Residual stresses in Ti+SS tubes were measured using neutron diffraction with the POLDI stress diffractometer on the neutron beam from the ISIS reactor of the Paul Scherrer Institute (Switzerland) [11]. The max residual stresses found was quite considerable: about 1000 MPa.

This prompted the development of an appropriate annealing thermal cycle to treat the samples prior to subject them to extreme temperature variations [12]. This solved the problem as no leaks were observed in the remaining three samples after EBW and thermal cycling in liquid helium [13].

Nb+Ti+SS TRANSITIONS

These results, while successful in the end, evidence some fragility of these junctions. A more conservative, much more solid, transition was then tried.

The new design consists in bonding Ti plates on both sides of a SS central plate. After machining and drilling a hole through all three plates, an inner Nb tube is inserted and EB welded to the Ti plates on both sides. In this way the junction area is much wider than in the samples described in the previous section and the explosion bond is between SS and Ti, which make a better joint than SS and Nb.

Two samples obtained using this procedure were produced by E.O. Paton Welding Institute (EWI Kiev, Ukraine) (see Fig.4).

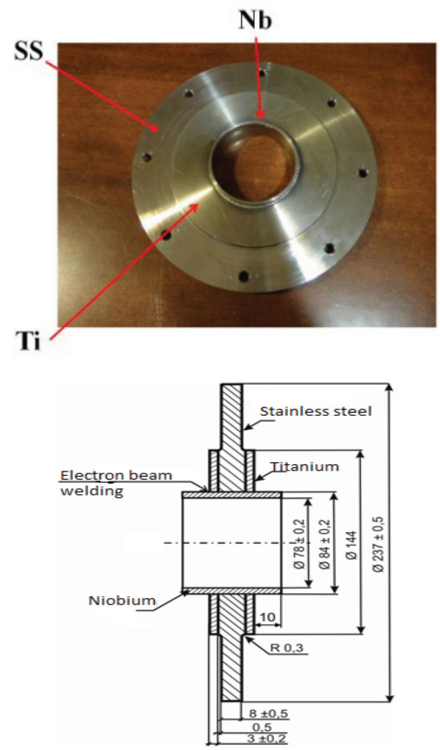

Figure 4: Nb+Ti+SS sample.

The two samples, after a preliminary check in Dubna, were sent to INFN-Pisa, where a specific equipment to test them was designed and built (see Fig.5).

With this equipment we are able to close a volume outside the Nb tube, between it and the SS flange, and make the vacuum inside; it's possible to mount the equipment on both sides of the SS flange to totally test the sample.

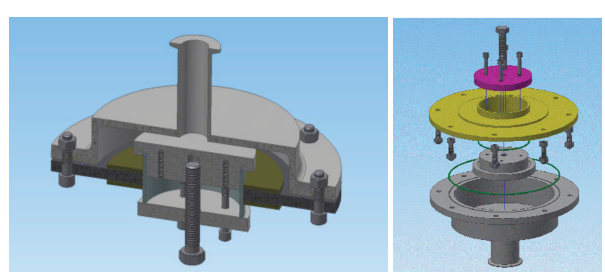

Figure 5: Nb+Ti+SS sample test set-up.

The test procedure (see Fig.6) was the same performed for the other metallic transitions: we connect the test set-up to a leak detection machine, we make the vacuum and we fill outside the sample with He gas. With this we searched for leaks at room temperature, after the

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immersion of the sample in liquid nitrogen temperature and after LN thermal cycles between them.

In all conditions we didn't observe any leaks; with a vacuum of 10^{-4} Torr the background leak rate was always $< 10^{-9}$ atm cm^3 sec^{-1}.

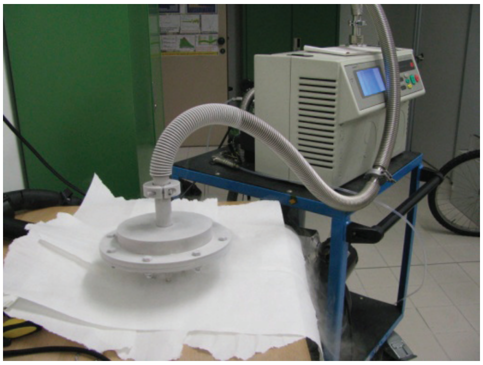

Figure 6: Nb+Ti+SS sample test at Pisa.

After these tests we brought the samples at INFN-Genova where a cryostat filled with helium liquid was available. Here (see Fig.7) we immersed both samples inside the cryostat in presence of liquid and gaseous helium at the equilibrium and we waited until the temperature probe connected to the sample reached 4.2 K. Then we pulled out the samples quickly and warmed them with the help of heat gun. We repeated this procedure two times.

Figure 7: Nb+Ti+SS sample test at Genova.

After these cooling cycles we checked again both samples for He-leaks. The situation didn't change, no-leaks were found.

CONCLUSION

During the last decade we developed a very solid transition between SS and Ti that can be used to replace the Ti material of He-supply line inside the ILC Cryomodule with SS. This transition was considered in the Fermilab design for next generation Cryomodule.

We also developed a bimetallic transition between the SS and Nb where some problems were found after the EB welding procedure due to the strong field of residual internal mechanical stresses in the material produced from the explosion bonding process.

With the last design (Nb+Ti+SS) we tried to make a transition less sensitive to these problems.

The explosion bonding of flat surfaces is easier and better controlled and the Ti intermediate layers allow welding by EBW the Nb tube.

The results of the tests performed on the first two samples produced with this design are completely successful.

Further analysis is needed and other tests are planned to simulate the operating conditions in an ILC Cryomodule. More samples with the same configuration are in production.

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