Report on visit to XFEL village, CEA-SACM/IRFU Saclay, 03-06.06.2013

Marc Ross, SLAC.

I visited the XFEL village in Saclay to observe the start of XFEL cryomodule assembly. My visit lasted four days and was hosted by Olivier Napoly. He is charge of the XFEL cryomodule (CM) assembly work package.

The purpose of the visit was to better understand how LCC-ILC can observe and possibly contribute to the upcoming roughly 2 year intensive CM production effort. I intended to achieve this purpose by talking with managers, engineers and technical staff about their objectives and concerns and to observe first-hand how the work is organized and how it proceeds. Fortunately, during this visit the 'roll-out' area assembly work on XM-2, the penultimate XFEL pre-production series cryomodule, took place.

Introduction

It is widely accepted that the GDE cavity R&D program was successful in proving the target accelerating gradient and production yield, albeit with limited statistics. Although GDE cryomodule average gradient and system test targets were also met, it became clear at the completion of the GDE program that because experience with cryomodules is quite limited further cryomodule R&D (including design work) is needed. The XFEL production cycle provides an excellent and unique opportunity to review technical assembly and test specifics and evaluate their performance and impact directly.

Technology transfer to industry and between institutions was the critical element of the GDE SRF program. For the next phase of ILC SRF development, CM production technology transfer will be an ongoing objective and it is expected this will be focused on activities at Saclay (assembly) and Desy (testing). Indeed, the cryomodule assembly effort at Saclay is contracted directly to Alsyom - Alcen, a French company with experience with high-technology system integration. The XFEL SRF cryomodules will be the first ones assembled by an industrial contractor. Saclay has a long history developing SRF with extensive production experience (for example with Spiral-II). However, they have not worked with SRF technology on a project of this size. Desy, Saclay and Alsyom intend to carry out a three-way technology transfer process during the ramp-up phase of the production cycle and they were in the midst of that during my visit.

CEA-Saclay program

The top-level XFEL project schedule calls for full cryomodule delivery by the end of Q1 2015. The Desy project managers have asked that the schedule be advanced to compensate for slow cavity and coupler production–start using Saclay-held contingency funds.

Saclay XFEL village is divided into six assembly zones: Coupler (CO – clean room), String Assembly (SA – clean room), Roll-out (RO), Alignment (AL), Cantilever (CA) and final Coupler installation (also abbreviated CO). The target assembly rate of one CM per week is achieved when work in each zone takes a week. Key steps for the roll-out assembly phase are: 1) Cavity alignment check (especially roll), 2) HOM filter RF tuning, 3) two-phase helium line welding and testing (including TüV - PED specifics), 4) cavity (helium vessel) hardware mounting (thermal sensors, multi-layer insulation, magnetic shielding, tuner and thermal interconnect braids. The quadrupole requires a few steps also. When these are complete the string is transferred from the string-assembly stand system to its cold-mass 300 mm gas-return-pipe hangers. The cold-mass itself is held from above by a heavy I-beam frame.

With the exception of HOM tuning, work on more than one of these steps can happen simultaneously. For XM-2, the HOM tuning work was done under static conditions – with no other string-work going on in parallel. The XM-2 string was rolled out of the clean room on 29.05.2013; HOM tuning adjustment was done in two days by Claire Simon 30-31.05. I arrived 03.06.

Roll-out activity observations and comments - details

1) Cavity alignment

Each cavity is connected to its neighbor by a short formed-stainless-steel (SS) bellows spool section. The inside of the bellows (made by BINP) is copper plated to reduce the beamline beam-impedance. I suspect the copper plating might be a source of particulate contamination, as it appears to have been with coupler bellows used in Fermilab HTS cavity tests in 2010. The string is leak-tested while still in the clean room, as one of the final checks, and then it is vented (either to nitrogen or argon – I don't remember which). Each cavity is ultimately supported by the large 'gas-return-pipe' (GRP) through four hanging clamps that squeeze four support tabs welded on the side of the helium vessel. Therefore position and angle of each cavity can be aligned in the final stages of cold-mass assembly (AL) but the individual cavity relative roll-angle and quadrupole roll-angle must be fixed in the clean room as part of string assembly. The tolerance is not specified but the Saclay group will maintain +/- 0.2 grad (+/- 3 m-rad). This angular maximum error corresponds to roughly to a 10 micrometer offset at the warm end of the coupler.

The cavity string assembly and roll-out supports are complicated. On the previous roll-out (XM-3) no string roll-restraint beyond the clamp on the quadrupole appears to have been used. For the XM-2 roll-out an 'inverted A' frame clamp was used to restrain each cavity (figure 1). While the roll tolerance is not tight, it is clear the inverted A frame restraints are cumbersome and difficult to adjust positively and consistently, i.e. a small tweak would loosen it. Each cavity also has a pair of support posts that appear to function as a kind of kinematic system. There are a number of adjustment mechanisms on the top of each support post. As these are tweaked and fixed in the clean room I was unable observe the adjustment procedure. Alsyom technicians commented on the awkwardness of the positioning system.

2) HOM tuning. See note above. I did not observe HOM tuning.
3) Two-phase helium line welding and testing
    a. Trimming

The 76 mm diameter two-phase He line is made of Ti and is part of the cavity/He vessel assembly. It is the primary heat – extraction cryogen line between the cavities and the heat exchangers and forms a manifold through the cryomodule. Since it is rigidly connected to the vessel there is a flexible bellows link in the two-phase line between cavities. During this step the lines are trimmed using an automated tubing trimming machine in order to set the distance properly (+/- 0.75mm) and to provide an fresh weld-prep oxide-free welding surface and a Ti formed bellows assembly is welded across each gap using an automatic orbital welder. This step must the 'certified' as a valid Pressure Equipment Directive (PED) step (more below). The welding work lasted about 2 days and was a major activity during my visit. Welding experts from Desy (Heiko Hintz (?) and Oliver Paschold(?) - MKS) started the work and trained Alsyom staff as a parallel effort. A qualified contractor (SEIV-Alcen), experienced in nuclear plant welding technology, completed the Ti welding. I believe SEIV will do the welding / weld certification during production.

Figure 1: Inverted ‘A’ frame. This device and the quadrupole mounts are the only string roll-restraint.

b. Twisting

I was disturbed by the apparent twisting of the string due to the weight and the lever-arm of the tubing trimming machine (although it is hard to separate this from the bending of the two-phase line). The weight of the modified – Makita tubing trimming machine (figure 2) is about 10 kg and the center of the two-phase line is about 300 mm from the center-line of the string. The inverted A frame support may not be positively clamped or pre-tensioned so the actual twisting force may differ from one cavity to the next. Both Desy and Fermilab use a lighter (5 kg?) pneumatically driven trimmer. The electrically-driven trimmer uses a reducing – gear system to drive the blades at about 1 Hz and this vibrates – it may produce more vibration than the pneumatically driven unit. It seems that using a retractable tool balancer to offset the weight of the Makita may help reduce the twist on the string (figure 3) When the Makita is dismounted the system appears to 'un-twist'.

Figure 2: Electric automatic tubing trimming tool – test cut procedure. The drill-motor is visible on the right side. The large central handle in the middle of the

picture is used to engage the cutting-tool feed. The cutters (each with different profile) rotate about 1 Hz and it takes a few minutes to cut and face – off the tubing.

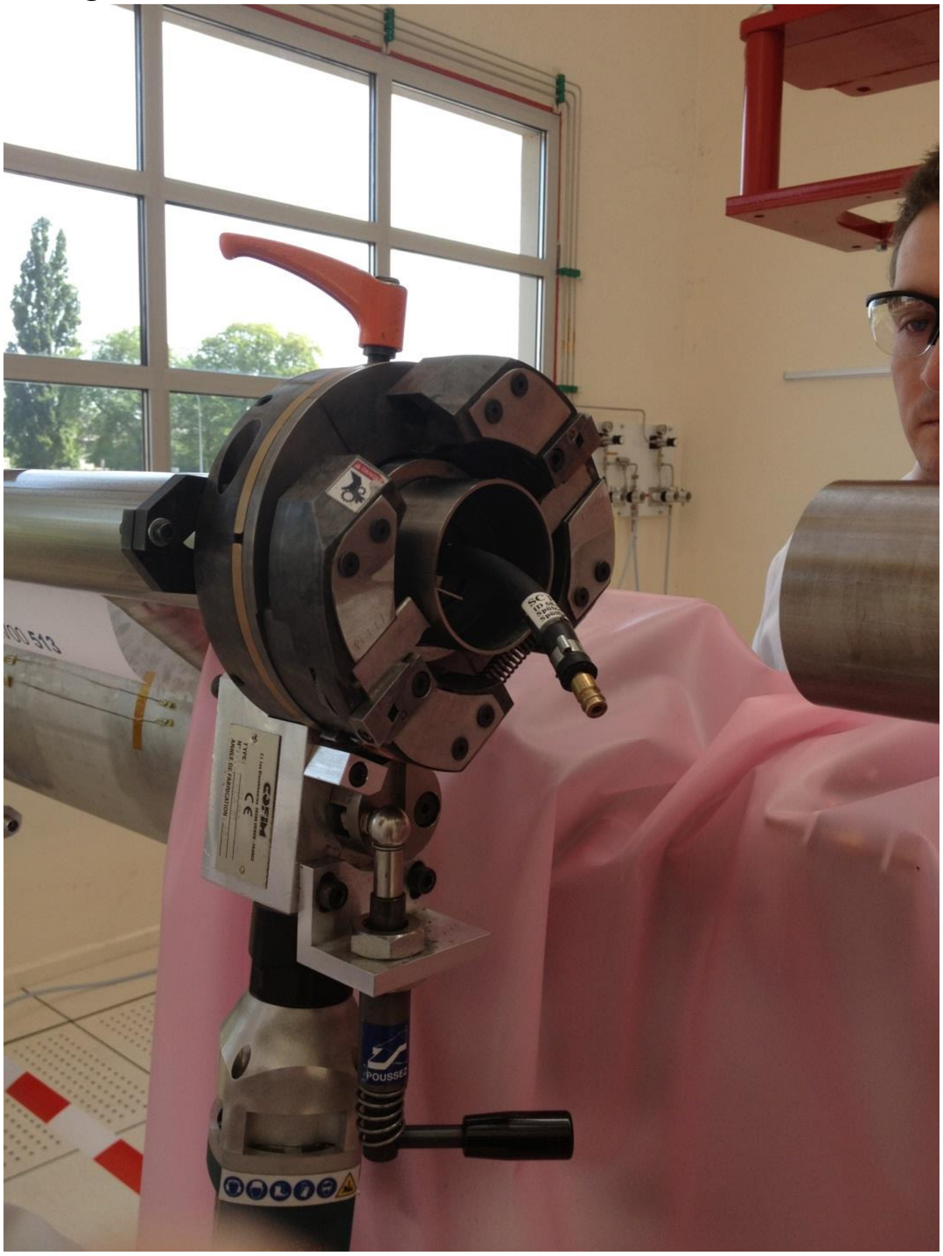

Figure 3: Two-phase line cutting about to start. The gap between the adjacent cavity tubing will very nearly be fit by the bellows weldment.

c. Leak check and handling

The Ti bellows weldment inserts used to connect adjacent cavities are cleaned, tested and packaged at Desy. It was a leak in this component that was troublesome for the CM-2 assembly at Fermilab. During my visit Tug Arkan

(Fermilab-TD) sent a dramatic video showing the leak-checking of the bad CM-2 Ti bellows weld seam (figure 4). Following his recommendation the Tech Division at Fermilab will clean these devices using 'beamline vacuum' procedure (even though their use is limited to cryo) and will require lint-free gloves for handling. Finding the leak in the CM-2 cryo-vacuum system was made difficult because it was easily sealed by fingertip moisture. A 'gloves-only' procedure is (apparently) not in force with the XFEL CM assembly. I believe it should be.

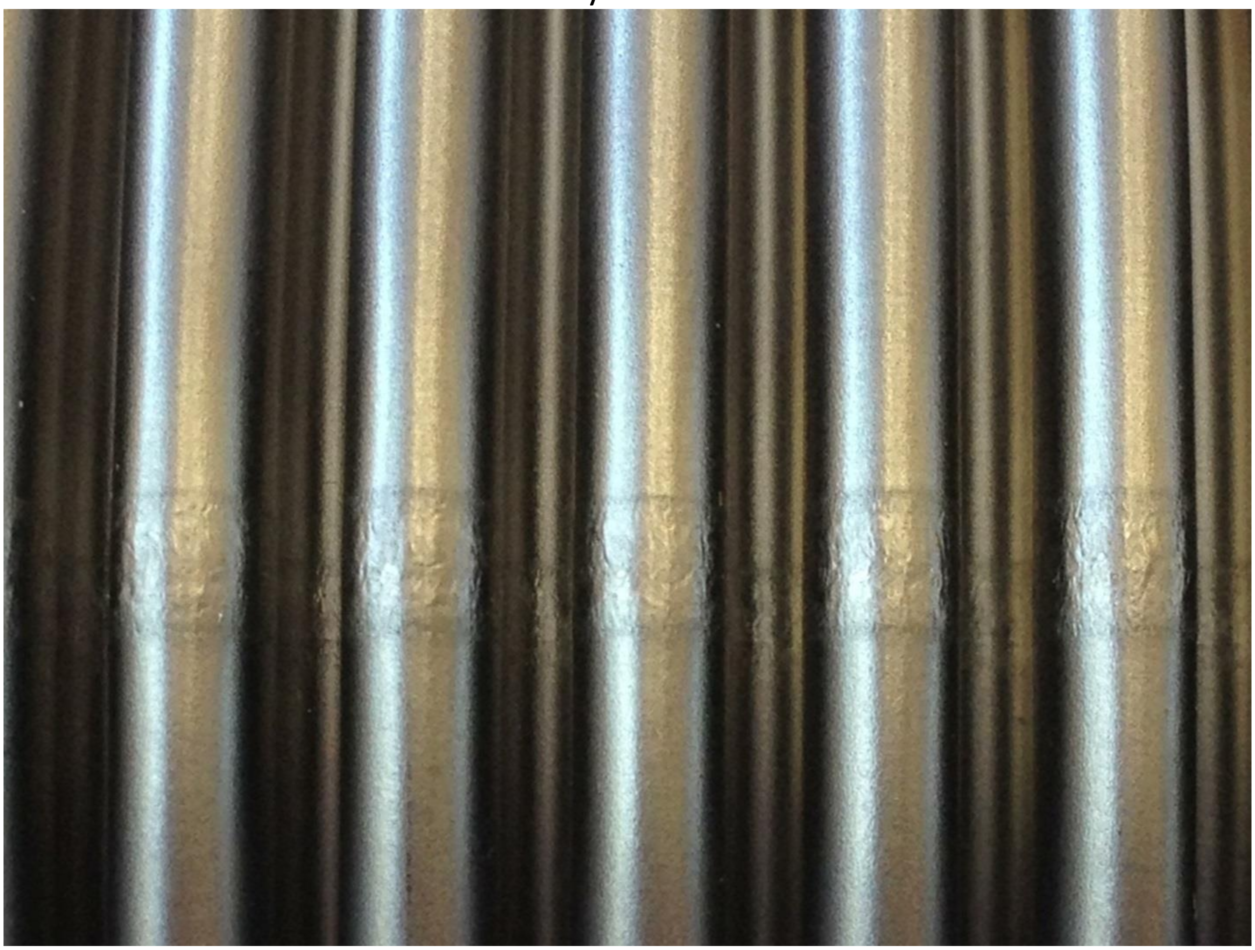

Figure 4: Titanium bellows showing the weld. This weld leaked in Fermilab CM-2

Leak check of the two-phase manifold Ti pipe is difficult because 18 cuts and welds are made 'in-situ'; two per cavity and two for the quadrupole. The quadrupole cooling lines are SS, not Ti, and the flanges at the end of the cryomodule are also SS. Several 'explosion-bond' tubing joints are used to adapt SS to Ti (material made by Asahi-Kasei). It was suggested by Cern (V. Parma) during the TDR CM assembly industrial studies to use a rubber clamshell leak checking procedure where helium is inside the entire manifold system and the pumped-out volume connected by a hose to the leak check mass-spectrometer is on in a small split-ring rubber clamshell that surrounds the outside of the weld (figures 5 and 6). The advantage of this is clear: assembly and weld leak-checking can proceed before the fabrication of the manifold is completed. An Ar-He 50-50 mix is used for Ti welding, so there is naturally plenty of He in the pipe. The disadvantage is that the clamshell must be moved from weld to weld and must be pumped down adequately after each move before that weld can be leak-checked. After testing several welds (~6) the rubber was saturated with He and this attracted the concern of the Alsyom technicians. They were unable to achieve the required He mass-spectrometer background. After sitting overnight, the clamshell appeared to have ‘cleaned-up’ and leak check activity could be resumed. The group will try to find ways to keep the clamshell-related background low. A second disadvantage is that the technician must be completely sure there is He inside the tube when starting to leak check. A high He concentration is not required, 10% is enough. A third disadvantage of this procedure, not an issue at LHC, is that it may be difficult to properly seal the rubber clamshell to the outside surface of the Ti pipe. This was not a problem at LHC because the non-standard tubing sizes used by CERN were more smoothly finished (machine finished). The XFEL Ti tubing has an ‘extrusion’ finish and may require ‘bostic’ (also known as duxseal caulking compound) or silicone grease. (Use of the latter is a concern in my opinion because it is hard to clean up and may mask real leaks.) (figure 7)

Figure 5: Rubber clamshell used for leak-check. The clamshell split is clearly visible in the larger, top, unit.

Figure 6: Clamshell leak-check device pumped down around a two-phase pipe weld.


Figure 7: Two-phase line before welding

d. Welding

Welding is done by a remarkable orbital welding machine (Arc Machines Inc, Pacoima, CA), coupled with an internal collet/ welding gas manifold (Westfalen) that serves to both hold the parts in place and to provide clean gas inside the tube during welding (figure 9). The welds made by this device look very clean – (figure 10) cleaner than the welded axial seam along the bellows themselves (where the leak was found in the CM-2 assembly) but not as clean as the Zanon Ti He vessel e-beam welds. These are quite impressive (figure 13) . The welding machine and procedure are TüV-qualified. Any modification to either must be re-qualified. Fortunately, Heiko himself has earned a TüV 'stamp' and can 'act on behalf' of TüV and qualify the changes made by his colleague, Oliver. This must be done, for example, following the exchange of the orbital welder tungsten electrode. An electrode lasts for about ¾ of the string, about 1 day, so it is important to be able to re-qualify the welding machine (figure 8). Each weld takes less than a minute. It is a one-pass weld with a small overlap section. The roll-out work requires three different orbital welding heads: two-phase Ti pipe, quadrupole SS feed line and the (much smaller) He vessel fill line.

Figure 8: Tungsten electrode of the orbital welder. Two electrodes are required for a string. The electrode must be replaced by a qualified welder.

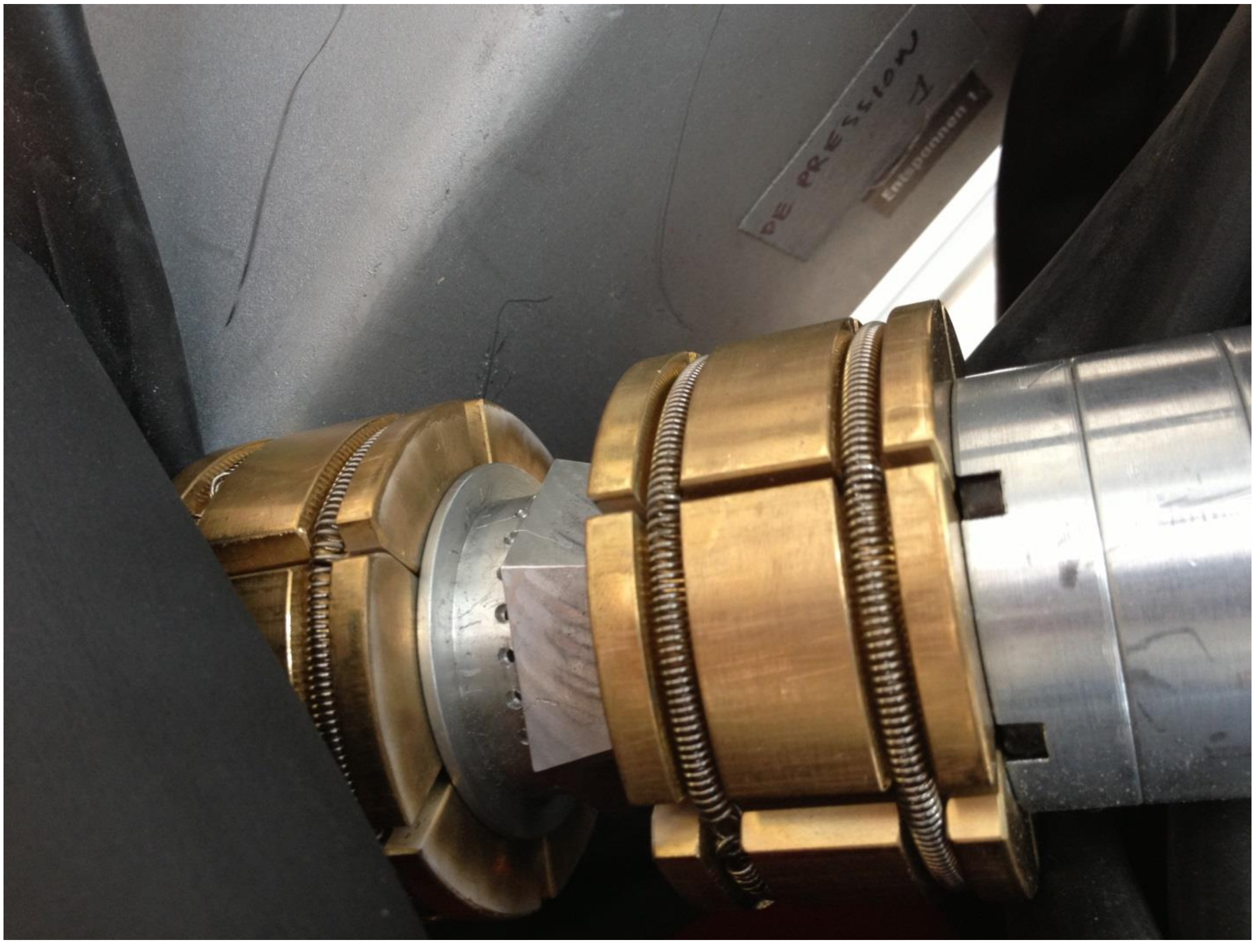

Figure 9: Internal gas manifold / collet assembly. This device (Westphal) both supports the tubing and provides Ar-He to the inside of the pipe during welding.

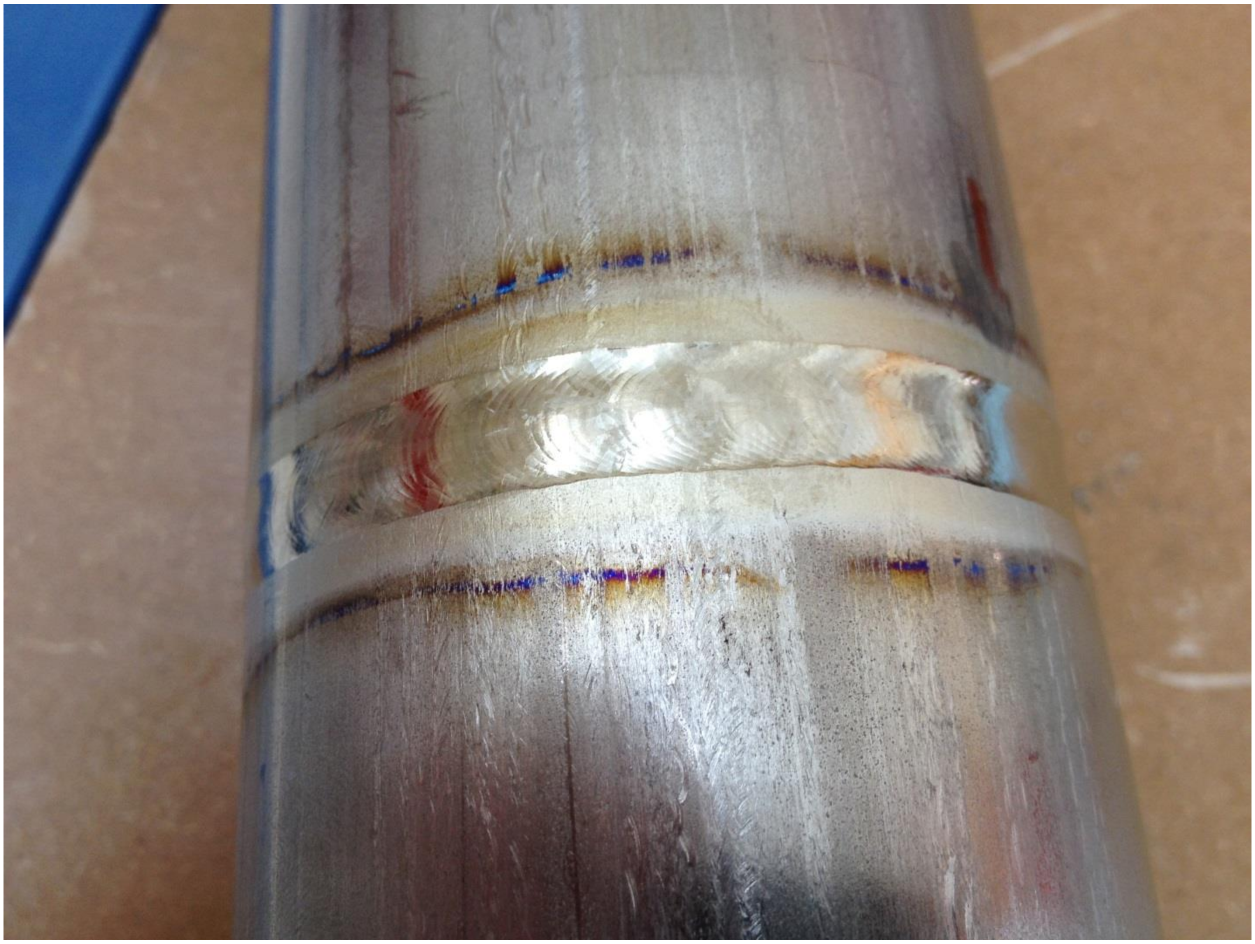

Figure 10: Ti two-phase pipe orbital weld results. The smooth ripples from the welder pulsing can be seen. Also light oxidation at the edge of the weld heat –affected zone can also be seen.

4) Cavity He vessel sensors, thermal and magnetic shielding

A pair of thermal sensors is glued to the surface of each He vessel. Thermal (MLI) is then fit over the vessel followed by the magnetic shield sheet-metal. Without the tuner, the tank is simple and this process took what appeared to me to be very little time – only a few hours for a pair of technicians. The shielding fits quite well and I believe it is much simpler than the 'blade-tuner' magnetic shielding. (figure 11)

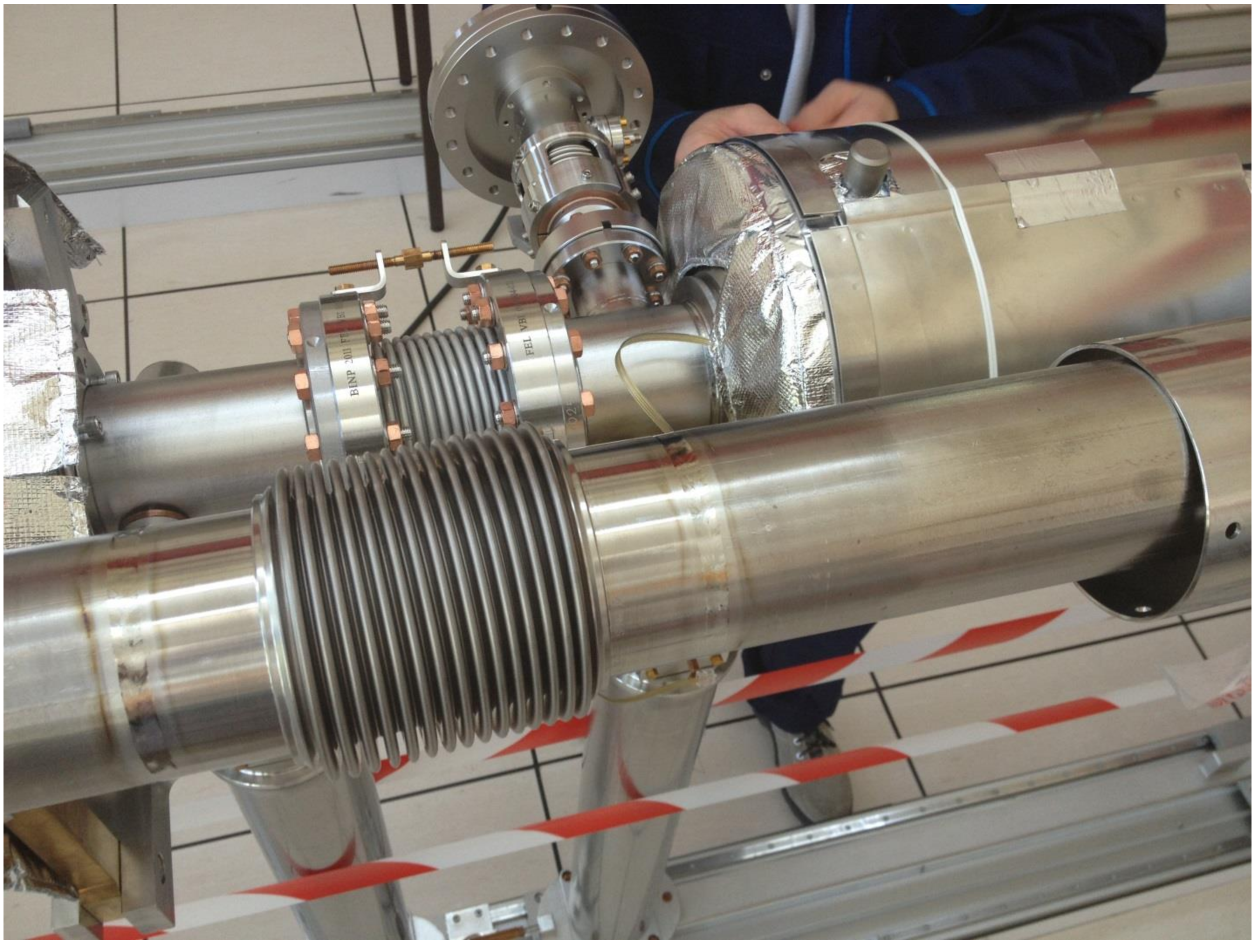

Figure 11: Completed welds and He vessel shielding.

<u>String 'shock absorbers'</u>

Olivier has instrumented the cold-mass in order to assess the handling process. We discussed crane 'landing', i.e. the process of bringing the load to rest following a move. The AL work area uses four large I-beam posts to hold the cold-mass carried. These can be adjusted to move up to 'meet' with the suspended load and may allow a softer landing.

There is an ongoing (many years) discussion about the effect vacuum (or lack of it - back fill) has on the adhesion of contaminant 'dust' particles. I believe there are published studies for example, from NASA, but these may be too specific to space technology. We should examine this more closely as it is unclear what 'shock absorber' performance is best.

<u>Hardware procurement</u>

Special clean-room-qualified and pre-packaged screws and related hardware have been selected by Desy for use in the beamline string assembly flanges (figure 12). It is not clear to me if the technology needed to produce this hardware is 'in industry'. Appropriately labeled screws are available, but expensive, and are not properly certified. It is not clear to me that appropriate 'surface contaminant (dust)' standards exist for this kind of component. I believe Desy have used internal MKS expertise to insure high quality parts and I fear this will be an ongoing difficulty during production. It is not clear to me that this approach can be adapted for mass-production. Of course this hardware is suspect in cavity degradation.

Figure 12: The end of the Ti tank, showing the weld, TüV stamp and flange hardware.

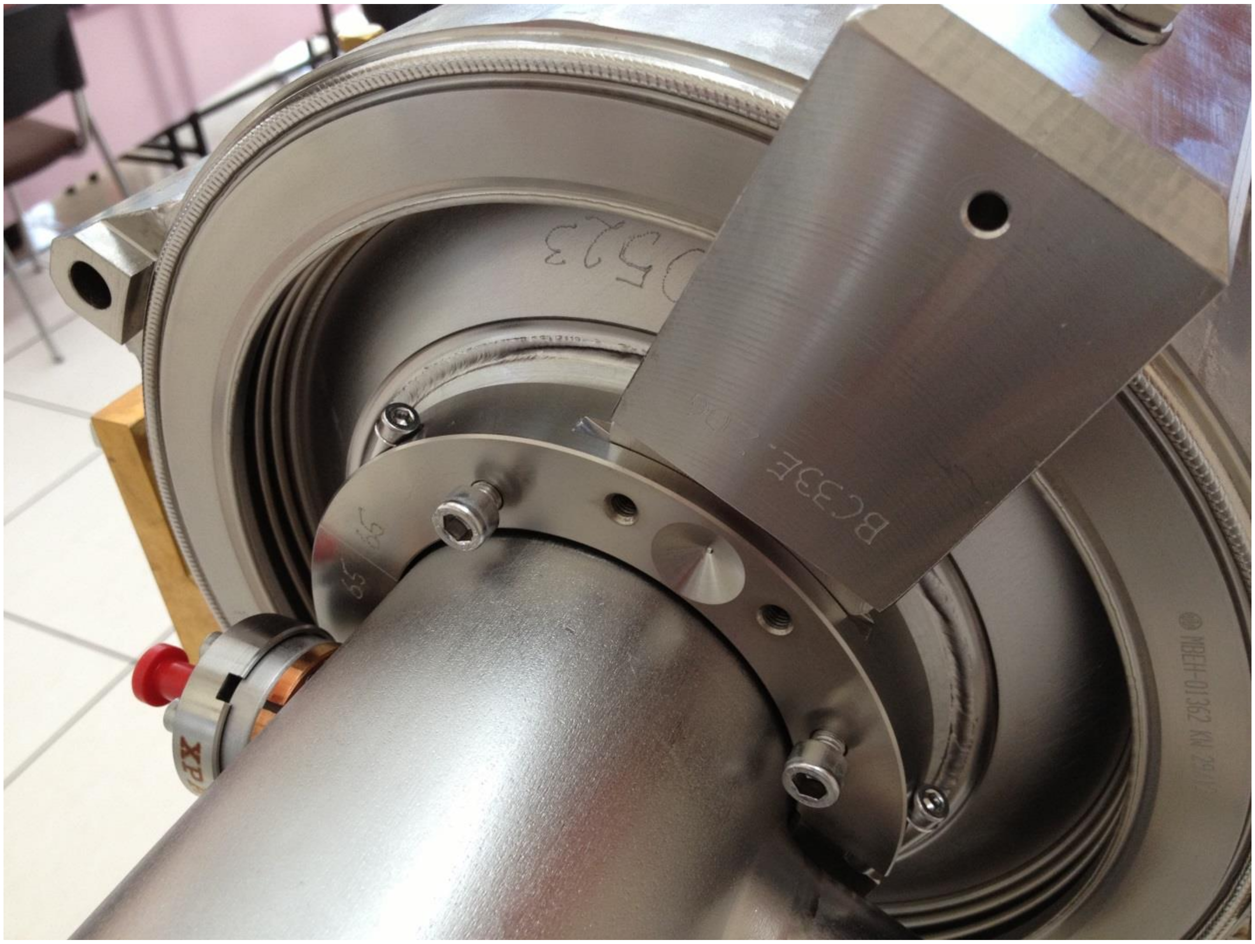

Figure 13: The other end of the He vessel, showing the support tab / slot, Ti weld (Zanon – the seam is clearly visible at the top center of the image) and vessel bellows.

<u>Coupler cover leaks</u>

It was reported that the coupler covers had leaked during the previous string assembly washing. (The outside of the cold part of the coupler is washed before being taken into the clean-room. (figure 14)

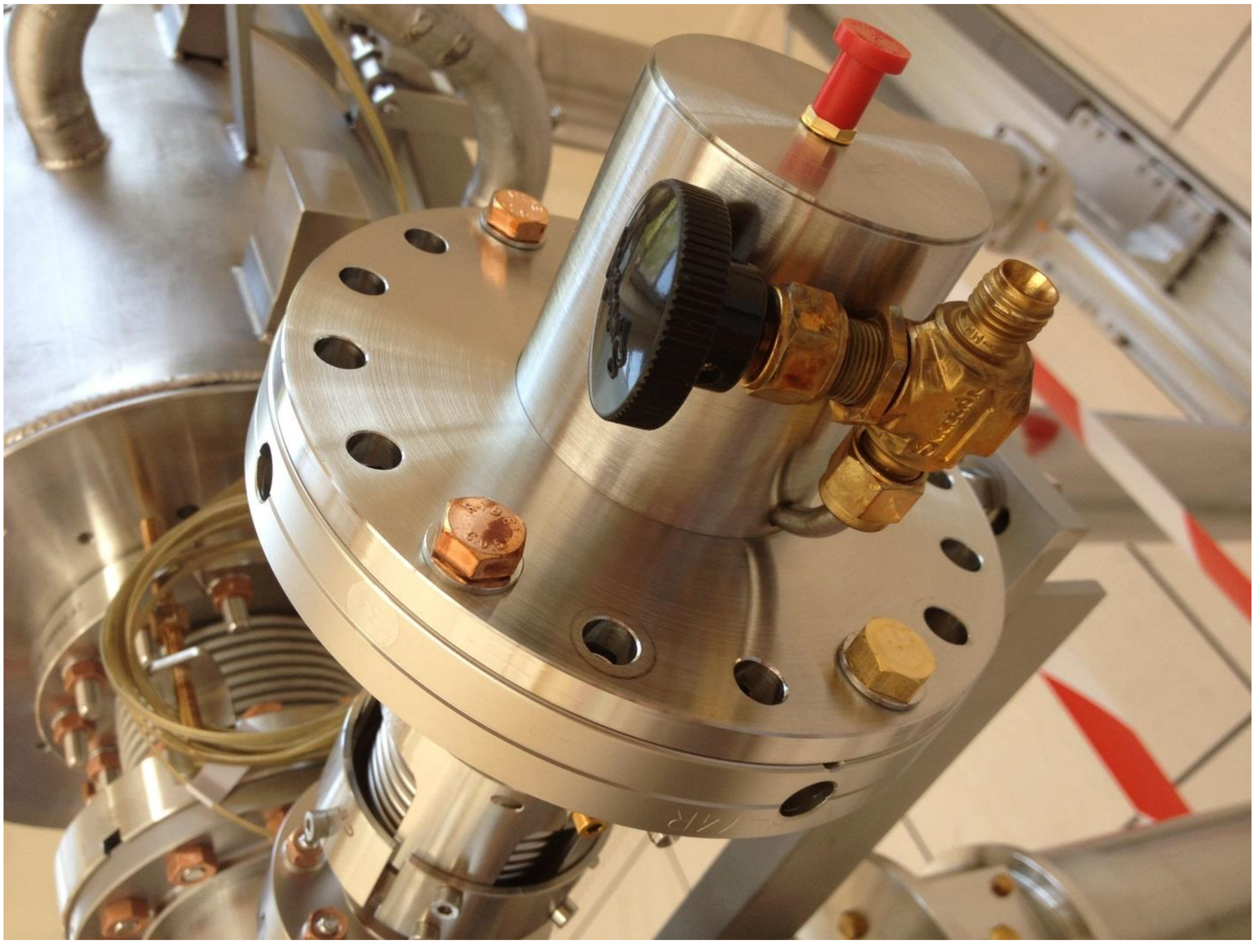

Figure 14: The coupler cover. Several of these leaked during the preceding assembly and contained moisture introduced during the washing cycle.