EXCHANGE AND REPAIR OF TITANIUM SERVICE PIPES FOR THE EXFEL SERIES CAVITIES

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Abstract

Longitudinally-welded 72 mm ID service pipes (HSP) made from titanium grade 2 is used by the two suppliers of the helium tanks for the EU-XFEL accelerator. From the perspective of the PED DESY is legally designated as the manufacturer and is responsible for conformity to all relevant codes. During module assemblies at CEA Saclay the orbital welds of the interconnection bellows between cavities showed pores with dimensions outside the specifications, set by DESY. These welds needed to be redone which caused a project delay of several months. The X-ray examination of the HSP showed that the pipes already exhibited many pores in the longitudinal welds out-of- DESY spec and some also out of PED spec. These pores were most likely the main cause of the problems in the orbital welds. It was decided to replace the extremities of the service pipes with seamless titanium tubes both on "naked" helium tanks as well as on tanks with cavities already welded in. At DESY more than 750 service pipes were exchanged over a period of 2 years. The qualification of the repair line according to PED regulation and the prove with RF test at 2 K that the repairs do not influence the high performance of the s.c. cavities were done.

INTRODUCTION

Each of the 800 superconducting cavities, ordered at industry for the EU-XFEL cold Linac, is installed into an individual helium tank, made of titanium and built under the regulations of the Pressure Equipment Directive (PED).

The helium tanks (HT), for the EU-XFEL cavities are manufactured by two companies. One half is made by E. Zanon SpA in Italy for their in house cavity fabrication. The second half of tank production, with slightly different weld geometry at the connection to the conical disk, were made by the companies CSC and E. Zanon SpA, both located in Italy. These HT were welded to EU-XFEL cavities at Research Instrument [1].

The 2 phase helium pipe, named helium service pipe (HSP), is one part of the helium tank. At the beginning of HT production only one supplier of pipes was available for this the required diameter of the HSP. During module assembly at the EU-XFEL partner institute CEA-IRFU in Saclay (France) [2] the HSP were welded to an interconnecting titanium bellow. The Titanium interconnecting bellows, manufactured according to the PED regulations as well, are welded between each pair of consecutive cavities to form the helium supply line for the cavity string [3].

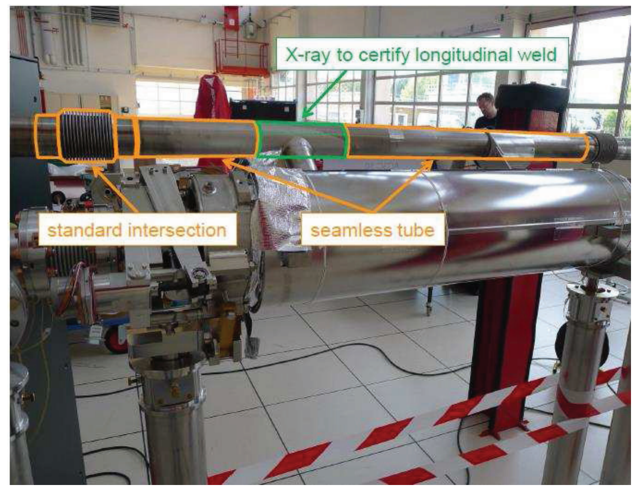

Figure 1: Sketch of the repair work, green part (Chimney) not exchanged during HSP repair.

All interconnection welds, made during module assembly, need to be X-rayed exanimated, since a pressure test cannot be applied any more to the cavity string at that stage of assembly.

During the first X-ray investigations (Fig. 2) it was found that many of the HSP longitudinal welds contained pores bigger than acceptable according to the DESY specifications. DESY took the decision to X-ray all the longitudinal welds of the HSP and remove all the pores bigger than 0.4 mm. These pores might be the origin of the problem for the pores, which were seen in the round welds at CEA. It was found that this required the exchange of all the pipe extremities (Fig. 1) with seamless pipes for about 620 already produced tanks. The exchange of the complete HSP with a seamless pipe was possible for about 180 tanks still under production.

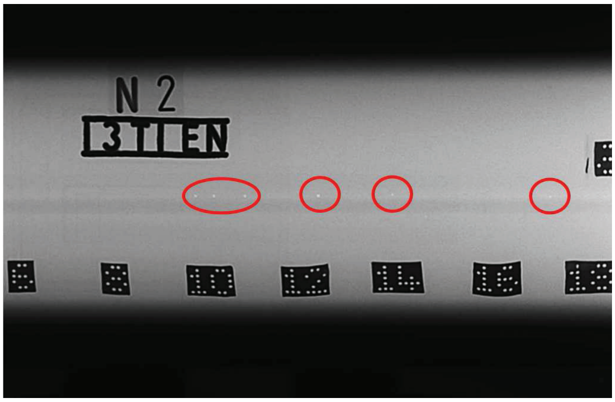

Figure 2: Example of X-ray picture from a service pipe with pores embedded in the longitudinal weld.

About seventy HSP showed pores in the so called chimney area (the connection between the main tank body and the HSP, see Figure 1) where no exchange was possible. Therefore an additional repair with manual TIG welding was performed at the company E.Zanon Spa following a TÜV qualified repair procedure.

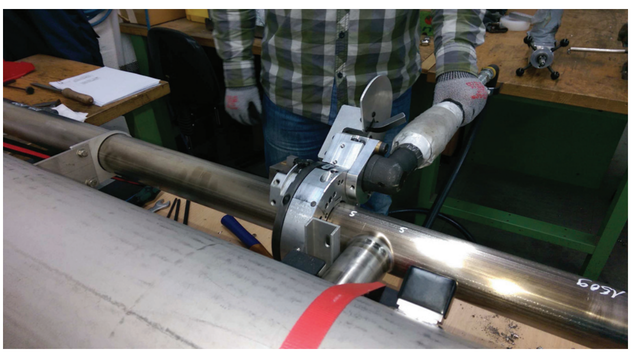

Figure 3: Cutting of helium service pipe at the position defined after X –ray examination.

EXCHANGE OF HELIUM SERVICE PIPE

To cure the problem of pores embedded in the longitudinal welds the exchange of the complete service pipe with seamless pipes would be ideal. Unfortunately, the space between the tank main body and the service pipe does not allow inserting a commercial orbital welding machine. Hence only the extremities are exchanged, leaving about 150 mm from the chimney axis on each side. The exact cutting position is defined looking at the longitudinal X-ray of the HSP and choosing a position where no pores are visible (Fig. 2), to reduce the risk of introducing new pores or increasing the diameter of the existing ones.

The pipes are cut with a commercial cutter (TriTool Inc., Mod.602.5SB) (Fig. 3).and the weld area is machined for planarity.

Figure 4: Helium tanks under HSP repair installed to weld cabinet and alignment support.

HSP Repair Procedure

The exchange of longitudinal welded HSP outside of the so called chimney area (Fig. 1) is done in five steps. The procedure is identical for individual helium tanks and tanks already welded to the 1.3GHz EU-XFEL resonators.

1. X-ray of longitudinal welds to determine pore free areas for the exact position of the cutting (Fig. 2 X-ray picture) to avoid the creation of pores while re-welding the remaining longitudinal weld at the chimney area.
2. Cutting the HSP at the defined position and machining for planarity. Cutting the seamless pipe to same length as the removed tube (Fig. 3).
3. Installing the helium tank to the weld cabinet. A dedicated support has been developed to guarantee the final alignment requirements of the pipe ends (Fig. 4).
4. Welding the connection from longitudinally welded- to the seamless pipe with an automatic orbital welding machine (Fig. 5+6).
5. Verification of quality of orbital welds by Non-Destructive Testing (NDT).

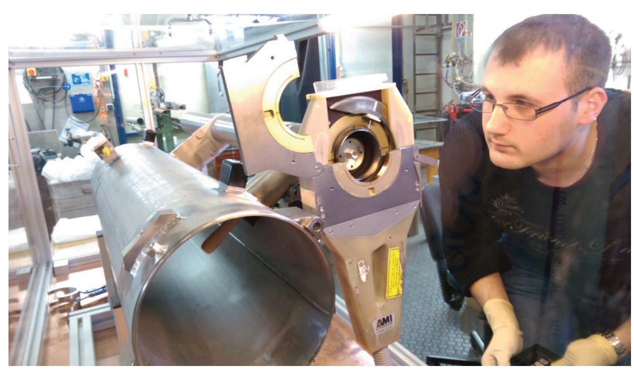

Figure 5: Alignment of welding needle of the orbital TIG welder to the weld plane at the chimney.

ISBN 978-3-95450-178-6

Non-Destructive Testing (NDT)

The NDT tests defined by TÜV and performed by certified personnel at DESY after the repair are:

- 100% Visual test (VT) of the outer and inner weld areas and surface via mirror (Fig. 7).
- 100 % Helium leak test (LT) of the individual welds.
- 100% X-ray test (RT) of the new orbital welds (Fig. 2).

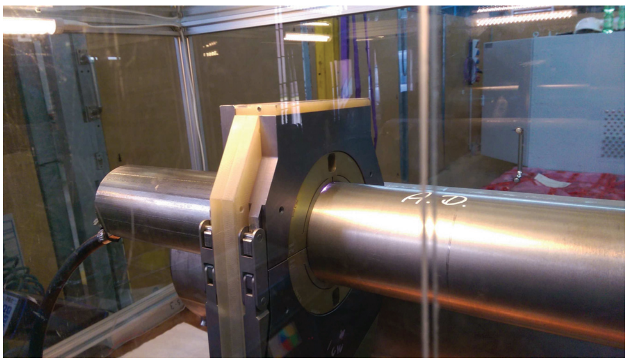

Figure 6: Helium service pipe during orbital welding (weld arc on top of tube).

ADDITIONAL REPAIR IN THE "CHIMNEY AREA"

The X-ray campaign on the longitudinal welds showed for about 70 tanks also non acceptable pores located in the so called chimney area. The space between connection tubes from tank to HSP chimney area is very limited and does not allow inserting commercial available orbital welding head.

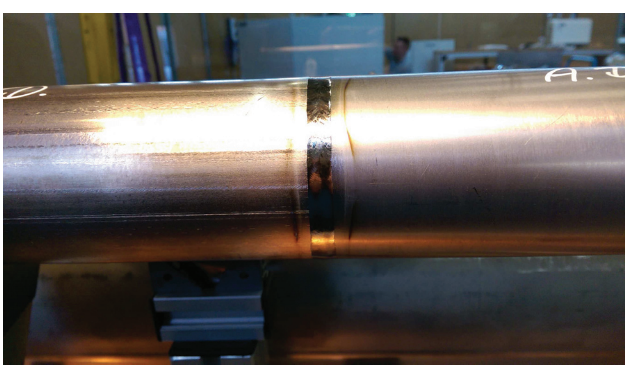

Figure 7: Orbital weld after exchange of HSP.

This repair at the chimney area on individual tanks as well as on tanks already welded to the cavities could only be done manually. This operation request well trained and experienced welders holding license from a notified body.

Here a special procedure (table 1) was developed and qualified by the company E. Zanon to do a local repair by grinding and manually re- welding with filler material.

Table 1: Repair Steps of Chimney Repair

X-ray re- examination of chimney area
Marking of pores area on tube
Grinding of the affected area of the tube to remove pore
Manual welding with filler
Visual testing and leak check of weld area
X- ray examination for verification of manual weld and removal of pores

VERIFICATION OF THE WHOLE PROCESS WITH ADDITIONAL RADIO-FREQUENCY (RF) TESTS

For individual helium tanks the qualification by VT, LT and RT of the individual, welds described above, demonstrates that the repair welds satisfy all the quality and safety requirements according to PED and DESY specifications (Fig. 8).

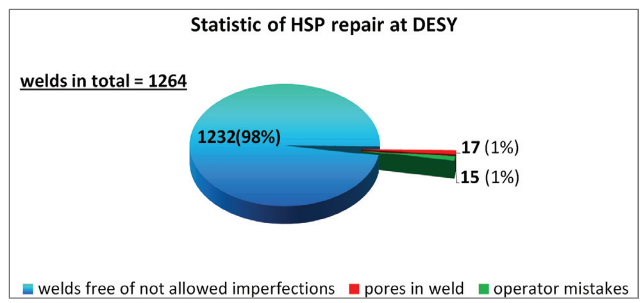

Figure 8: Statistic of HSP repair at DESY.

Beside this mechanical proves it had to be shown that the repair, done on helium tanks where the s.c. cavities are integrated to, did not influence the performance of the cavities.

More than 400 cavities were already welded to a tank and tested at 2 K when the HSP repair campaign started. Moreover, the running production of cavities integration to tanks could not be stopped to avoid additional delays in the project. It was also not possible to redo all RF tests at 2 K for these cavities. Only on a statistical basis RF tests were done to qualify the overall workflow and handling.

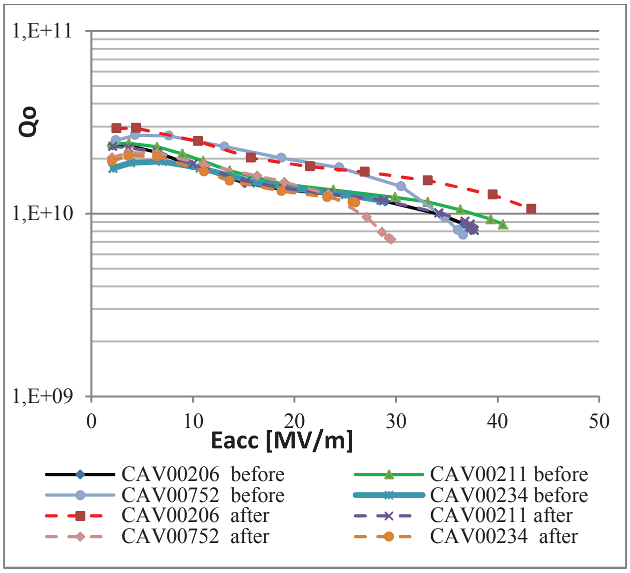

Figure 9: Example on Rf test for statistical prove of resonators before and after HSP and chimney repair.

The exchange of HSP end was done in DESY at building 55. Due to the repair action a large number of cavities needed to be stored at DESY for some time. Not all of them could be stored at the test area AMTF where X- ray control of the welds took place. For storage of cavities for X- ray examination, removal of HSP and preparation for hand over to CEA new adequate storage space had to be set up. Cavity storage space for the repairs of HSP was set up in containers in front of AMTF, in the XTL Mock Up tunnel near to AMTF, in building 55 stock area for HSP exchange and in building 80 b about 1 Km away from AMTF and Building 55.

Table 2: Test Results of Cavities after Chimney Repair

	Before repair		After repair	
CAV_FE	E(acc) / [E(usable)]	Q0	E(acc) / [E(usable)]	Q0
No.:	[MV/m]		[MV/m]	
00033	34 [28]	$7{*}E^{+09}$	39 [37]	$9{*}E^{+09}$
00082	35 [27]	$1{*}E^{+10}$	33 [29]	$9{*}E^{+09}$
00124	31 [29]	$6{*}E^{+09}$	32 [29]	$6{*}E^{+09}$
00133	38 [31]	$6{*}E^{+09}$	42 [34]	$9{*}E^{+09}$
00209	31 [22]	$8{*}E^{+09}$	33 [25]	$8{*}E^{+09}$
00211	41 [38]	$9{*}E^{+09}$	38 [35]	$8{*}E^{+09}$
00695	29 [25]	$7{*}E^{+09}$	30 [27]	$8{*}E^{+09}$
00752	37 [32]	$8{*}E^{+09}$	30 [27]	$7{*}E^{+09}$
00580	33 [20]	$5{*}E^{+09}$	34 [32]	$6{*}E^{+9}$
00015	29 [29]	$1{*}E^{+10}$	28 [28]	$1{*}E^{+10}$
00234	29 [29]	$1{*}E^{+10}$	26 [26]	$1{*}E^{+10}$
00034	37 [34]	$8{*}E^{+09}$	34 [34]	$1{*}E^{+10}$
00206	38 [34]	$8{*}E^{+09}$	40 [31]	$9{*}E^{+09}$

The internal transports at DESY were organized on a weekly base, where up to two batches (each batch with six parts) of cavities are transported between AMTF, building 55 and building 80b.

Figure 10: Overview of transport ways.

Table 3: Overview of Transport Distances

Transport	distance
AMTF – Bldg. 55	445m
AMTF – Mock up Bldg.	330m
Bldg. 55 – Bldg. 80b	1450m
Bldg. 80b – AMTF	1700m

Moreover, since the cavities for chimney repair are not only internally transported at DESY, but travel back and forth to Italy, where the company E. Zanon is located (Fig. 10), the cavities with chimney repair had to keep the performance without retreatment. On statistical basis cavities coming back from repair are retested after return from repair in Italy. From the seventy cavities with need of chimney repair more than one third is requalified by RF test at 2 K (Table 2).

The majority of tests done until August 2015 reproduced the acceleration gradient from test´s done before chimney repair (Fig. 9) within the tolerances of RF test. Only two cavities showed different values.

The degradation of cavity CAV-HT00752 can be explained by impact in transport or handling. At CAV_FE00206 the performance increase by about 7 MV/m without additional treatments (Fig. 11) is unexpected and under investigation. Most likely the change of the Kt factor (coefficient of expansion) between the two test´s is responsible for this increase of gradient measured after chimney.

ISBN 978-3-95450-178-6

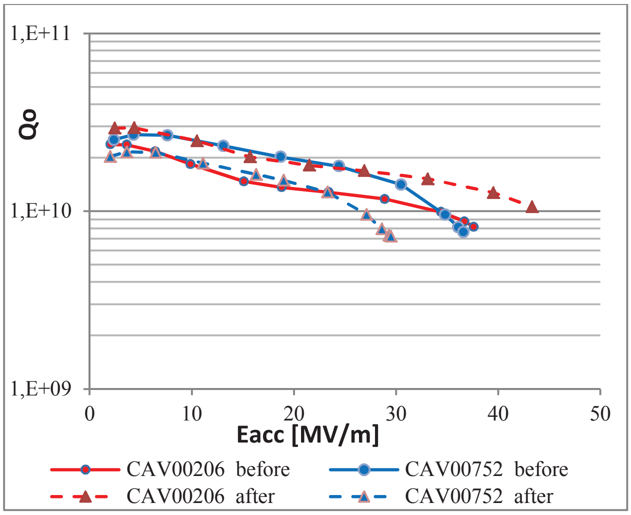

Figure 11: Test result of cavities with performance changes after chimney repair.

SUMMARY

816 helium tanks have been fabricated in industry for the EU-XFEL resonators. After a problem with pores in the longitudinal welds of the helium service pipe was observed, the decision was taken by DESY experts to replace the affected pipes with seamless pipes. Up to 180 service pipes were exchanged completely with seamless pipes already during ongoing fabrication of helium tanks. On the seven hundred tanks already finished, from which 443 were already welded to the cavities, the extremities of the service pipes were exchanged at DESY, complying with the PED regulations and the DESY quality requirements (no pores bigger than 0.4 mm are allowed).

Pores out of specifications located in the region between the exchanged extremities (chimney area) were locally repaired by the company E. Zanon.

RF tests of cavities after cutting and welding the service pipes and lots of transports showed that cavities did not change their RF performance or showed small changes in the region of acceptance gradient for module.

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