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Summary of QRL 7-8 repair and re-installation leak test results.

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Keywords: leak test, QRL

Summary

This note describes the leak tests that have been performed during the repair and re-installation of QRL sector 7-8 during 2005 and 2006. The leak tests were performed in UX65, where the pipe elements were refurbished before re-installation, and in the tunnel. A variety of leaks have been detected, localised and repaired in the tunnel, including weld defects, accidentally drilled holes and imported leaks in previously tested components.

1. Introduction

QRL sector 7-8 was the first sector installed in the LHC tunnel. In view of several systematic non conformities that could not be repaired in situ, it was decided to open all interconnections, remove all elements (pipe elements, fixed points and service modules) from the tunnel and re-install them following repair in a workshop environment.

The QRL in sector 7-8 is consists of nine sub-sectors, from sub-sector A on the point 8 side to sub-sector I on the point 7 side. The connection of sub-sector A to the cryogenic installations in point 8 is via the junction region, see figure 1.

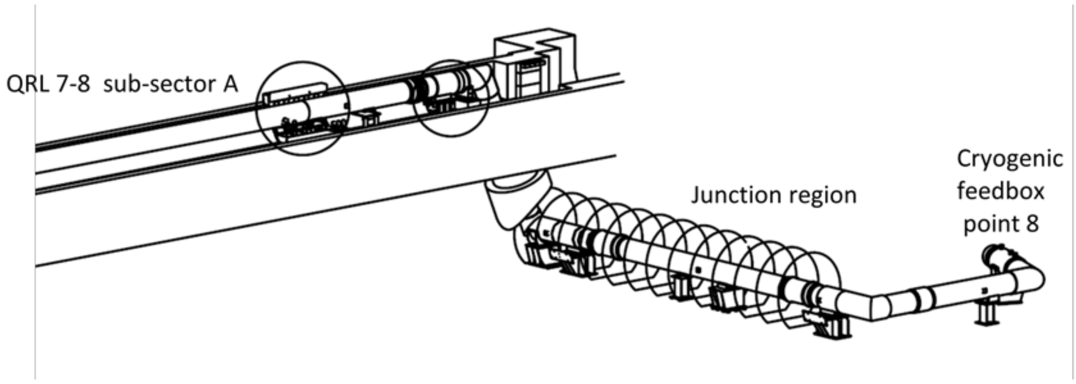

Figure 1 – QRL sector 7-8 is connected to the cryogenic feedbox in point 8 via the junction region.

The pipe elements and fixed points were repaired in UX65 by an external firm. TE-VSC (AT-VAC at that time) trained and supervised a Polish team from the interconnect QA collaboration that performed the leak tests in UX65 of the various repairs and modifications of the QRL elements. The service modules and junction region elements were repaired by CERN workshop staff in building 110. TE-VSC performed the leak tests on the repaired elements in building 110.

Re-installation leak testing in the tunnel was performed partly by TE-VSC staff and partly by a team of contractor personnel, except for the re-installation in the junction region where all testing was performed by TE-VSC staff.

This note summarises the leak test activities and results of the leak tests in UX65 and the re-installation leak test activities in the tunnel. It complements the test procedure that was written for the initial QRL installation in sector 7-8 [1]. This note does not include the leak test activities in building 180 or the re-installation leak test activities in the junction region.

2. Leak testing of pipe elements in UX65

2.1 Leak test of lines B and F

Following their removal from the tunnel, all pipe elements were dismantled. Line B was inspected with an endoscope for weld defects while line F was systematically replaced with a new one. Lines C and D were re-used without any further intervention. Depending on the results of the endoscopy of line B, a leak test was sometimes required.

Two stainless steel end domes, supplied by Air Liquide[1] were mounted on both ends of the pipe element to close the vacuum envelope, see figure 2. The vacuum envelope was pumped with a turbo molecular pump, backed by a rotary pump during pump-down and by a leak detector during the leak test. During the actual leak test, line B and line F were pressurised with 2 bar abs of He.

Figure 2 – Stainless steel end dome to close the end of a QRL pipe element

Part of the repaired pipe elements have been tested with different end domes, designed at CERN, see figure 3. This aluminium alloy dome [2] was lighter in weight and therefore easier to manipulate. The extremities of lines C and D remained inside the vacuum envelope. This reduced the number of pipe feedthroughs and hence reduced the time needed to mount and demount the end domes.

[1] TE-VSC has subsequently purchased a 2nd set of end domes on CERN purchase order CA 1345703.

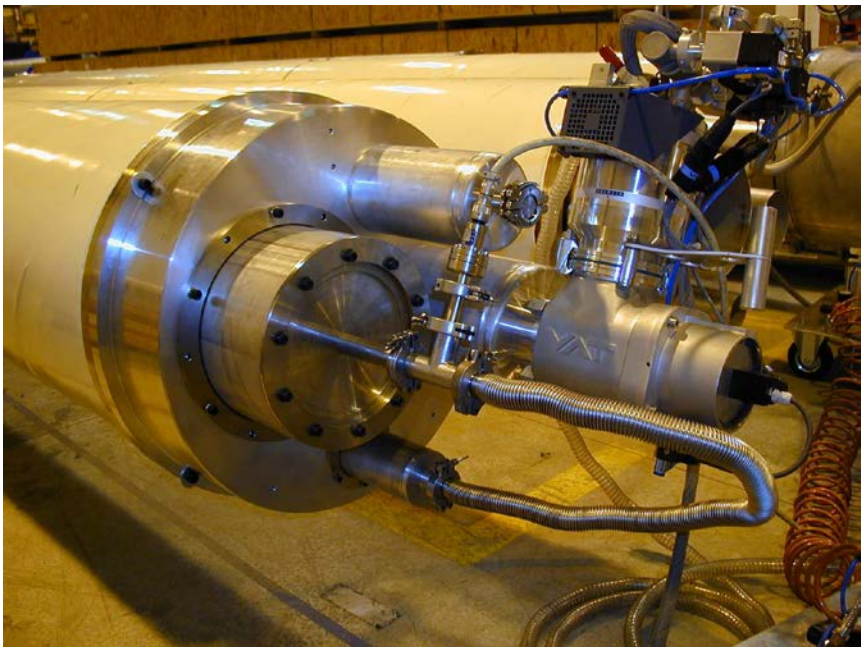

Figure 3 – Aluminium alloy end dome to close the end of a QRL pipe element

Figure 4 shows a schematic of the test setup, the full test procedure is described in [3].

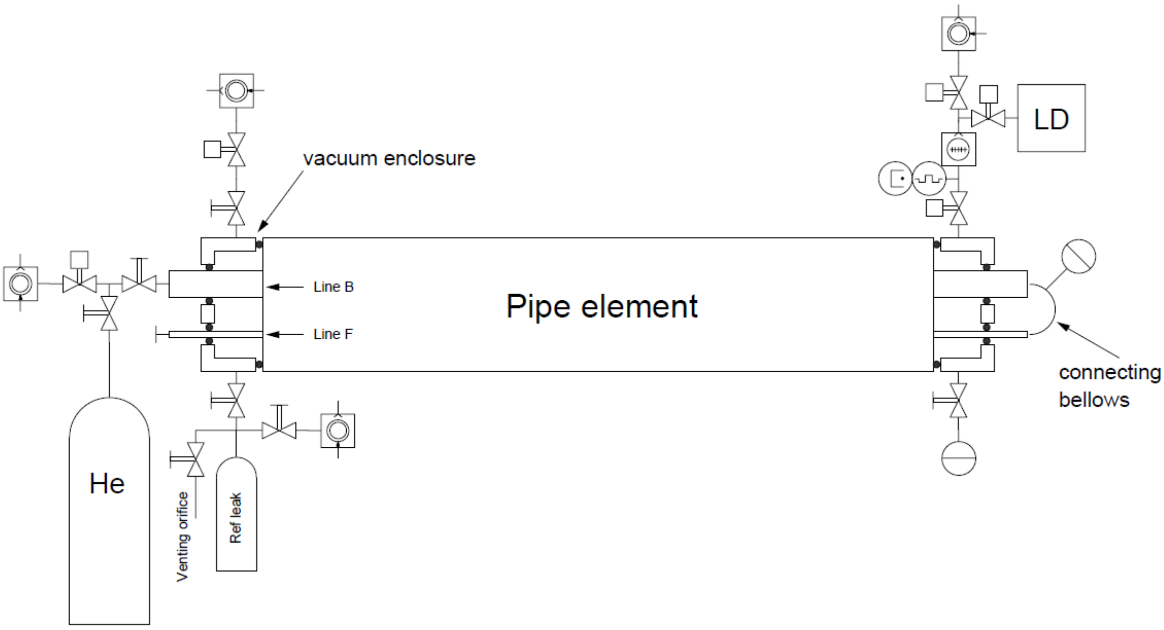

Figure 4 – Schematic of the test set-up for leak test of lines B and F in repaired pipe elements.

During the leak testing activities it became evident that the surface of the QRL process lines was not always adapted for proper sealing with elastomer O-ring seals. The use of vacuum grease would help but raised worries about the possible creation of welding defects during subsequent welding operations.

A test program was set up in collaboration with EN-MME. The results showed that the use of silicone based vacuum grease, followed by removal with a suitable solvent was acceptable in view of subsequent welding operations [4].

2.2 Leak test of process line extensions

In some cases the process lines had to be extended by about 300 mm as part of the repair. The required butt welds were tested with purpose made symmetric clam shells [5].

The template for the leak test certificate is attached as appendix A.

2.3 Leak test of welded rings on process lines

The repaired pipe elements for sector 7-8 have all been equipped with a stainless steel ring welded to both ends of the process lines. This design allowed for tunnel welding without protective atmosphere inside the process lines.

The welds of these rings were leak tested with purpose made test tools that sealed on the outer ring surface and on the inner tube surface. In view of its small volume, the tool was pumped directly with the leak detector.

The full test procedure is described in [6].

2.4 Leak test of welded S-rings on cryostat flanges

The repaired pipe elements for sector 7-8 have all been equipped with a so-called S-ring, welded to the cryostat flanges on both extremities. This design allowed for tunnel welding without protective atmosphere inside the cryostats.

A dedicated ring shaped tool [7] has been designed and built which allowed for under vacuum testing of the S-ring weld. In view of its small volume, the tool was pumped directly with the leak detector.

The template for the leak test certificate is attached as appendix B.

3. Leak testing of compensators in UX65

The compensators recovered from sector 7-8 were refurbished in UX65. The refurbishment consisted of adding welded rings to both ends to allow for tunnel welding without protective atmosphere inside the process lines. In addition, part of the compensators were extended by adding a butt-welded extension.

The compensators were sufficiently rigid to allow for an under vacuum leak test. One end was closed with a plug that would seal on the outer surface of the welded ring. A pumping tool, also sealing on the outer surface of the welded ring, was mounted on the other end. The small diameter compensators of lines F (Ø84), E (Ø84) and C (Ø104) were pumped with the leak detector. The larger diameter compensators of lines D (Ø154) and B (Ø273) were pumped with a turbomolecular pump, backed by a rotary pump during pump-down and by a leak detector during the leak test.

The template for the leak test certificate is attached as appendix C.

4. Leak testing in the tunnel

Reinstallation leak tests in the tunnel started on 3 June 2005 with the first clam shell tests in sub-sector B. Testing was concluded 322 days later on 21 April 2006 with the test of 3 repairs on the vacuum envelope of sub-sector I.

4.1 Leak test method

Tunnel leak testing of the re-installed QRL was theoretically to be done in the following sequence:

1. Under vacuum testing of the process lines of a “zone” (a quarter of a sub-sector with a length of around 100 m and containing typically 10 interconnections to be tested). This test was to be performed 4 times to cover a full sub-sector.
2. Under vacuum testing of the process lines of a full sub-sector (with a length of around 400 m and containing the 3 interconnections between the 4 zones to be tested).
3. Under vacuum testing of the vacuum envelope of a full sub-sector.
4. Global testing of the process lines of a full sub-sector (vacuum envelope under vacuum and process lines filled with helium).

This sequence was to be repeated nine times to cover sub-sectors A to I of sector 7-8.

During the start of the interconnect tunnel welding activities, a quick feedback was requested on the leak tightness. The first welds were therefore tested with clam shells (see section 4.2).

It was initially foreseen to place plastic pockets around the process lines in all interconnects under test. This turned out to be the most time consuming part of the entire leak test. Following a number of system calibrations it was found that lengths up to 100 m could be tested with a He spray, for longer lengths the He was applied in plastic pockets.

In case of very large leaks, when the obtainable vacuum was not good enough to perform an under vacuum localisation, the volume concerned was slightly pressurised with dry compressed air and the leak localised with bubble spray. Figure 5 shows an example.

Figure 5 – Localisation with bubble spray of a large leak in the interconnection weld of a process line.

On occasions where parts had to be replaced (e.g. a number of compensators but also an entire service module with an internal leak), clam shell tests were performed to test the new connections of the replacement part.

4.2 Tooling

The following tooling and equipment were used for the leak testing activities:

- Clam shells (sealing on the OD of the welded ring and process line Ø84, Ø104, Ø154 and Ø273 mm) for testing of the interconnection welds of the process lines [8].
- Pump-out tools for pumping the process lines from one end and closing them on the opposite end [9]. These tools seal on the inner tube diameter of the process lines. Figures 6 and 7 show the tools in place. The vacuum valves in figure 6 are closed and the tools act as plugs. The vacuum valves in figure 7 are open and the tools act as pump-out tools. The penetration of the longitudinal weld in the process lines would sometimes make it impossible to install the pump-out tool. In such cases we would locally smooth the inner surface with a rotary grinder.
- Mobile primary pumps (60 m^3/h) for rough pumping of the insulation vacuum envelopes.
- Turbo molecular pumps (250 l/s) to pump the process lines and the insulation vacuum envelopes.
- Mobile He leak detectors (with sniffers for accumulation tests when needed).
- Bubble spray (Mille Bulles, SCEM 58.81.09.900.6).

Figure 6 – Pump-out tools acting as plugs installed on the process lines. The tool on line F (bottom) is equipped with a reference leak for a system calibration

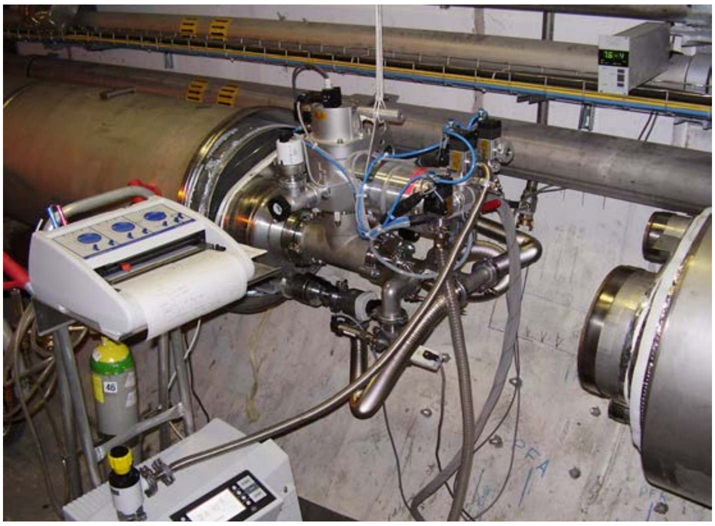

Figure 7 – Pump-out tools installed on the process lines. The tool on line B (largest diameter) is equipped with a manifold connecting the turbomolecular pump to all process lines in parallel.

4.3 System calibrations

A number of measurements have been performed to check the response times of the leak tests on such long tubular volumes and validate the test procedure.

The pumping group with leak detector was connected to one end of the volume under test (figure 7). A reference leak was placed behind a closed vacuum valve on the opposite end (figure 6). The reference leak was pumped out with a 2-stage primary pump to <1E-2 mbar. The vacuum valve, isolating the pumped reference leak, was subsequently opened while the leak detector signal was recorded.

The response time t_r is usually defined as 3 times the system's time constant, corresponding to the obtention of $(1 - e^{-3}) = 95\%$ of the full signal:

$$t_r = 3\sigma \quad (1)$$

The system's time constant σ is defined as the pumped volume V divided by the effective pumping speed S_e:

$$\sigma = \frac{V}{Se} \quad (2)$$

The effective pumping speed is determined by the pumping speed S_p at the pump flange and the conductance C of the pumped volume. The conductance consists of the pump-out tooling (C_t) and the process-line (C_{pl}) itself:

$$\frac{1}{Se} = \frac{1}{Sp} + \frac{1}{Ct} + \frac{1}{Cpl} \quad (3)$$

Flow conditions depend on the mean free path of the gas molecules, given by:

$$\bar{\lambda} = \frac{6.7\ 10^{-5}}{\bar{p}} = \frac{1.3\ 10^{-4}}{p_{max}+p_{min}} \quad (4)$$

The vacuum pressure at the pump (P_{min}) was typically ≤1E-4 mbar, the pressure at the opposite end (P_{max}) was estimated at ≤1E-3 mbar. The average mean free path is then calculated to be 0.12 m. Since this value is at least a third of the diameter of all process lines, the flow can be considered molecular [10].

For molecular flow, the air conductance of the process line [m^3/s] depends on its length L, diameter D and Clausing factor α [10]. Since for our tests L/D > 100, the Clausing factor is 1.

$$C_{pl\_air} = 121\frac{D^3}{L}\alpha = 121\frac{D^3}{L} \quad (5)$$

The molecular flow conductance for He is higher than the conductance for air (scales with the square root of the inverse ratio of the molecular masses) [10]:

$$C_{He} = 2.67C_{air} \quad (6)$$

The molecular flow conductance C_t of the pump-out tooling is estimated at 0.5 m^3/s for line B (DN 100 elbow and DN100 butterfly valve) and around 5E-3 m^3/s for the other lines (KF40 flexible hose and KF40 right-angle valve).

The pumping speed for nitrogen at the ISO-K 100 pump flange of an Alcatel ATH300Ci turbo molecular pump is 0.25 m^3/s. The He pumping speed S_p is specified at 0.215 m^3/s [11].

Combining equations (1) to (3), (5) and (6), we obtain:

$$t_r = \frac{3}{4}\pi D^2 L\left(\frac{1}{0.215} + \frac{1}{Ct} + \frac{L}{323D^3}\right) \quad (7)$$

With geometrical dimensions in m, conductances and pumping speeds in m^3/s, t_r is calculated in seconds.

Figure 8 shows the calculated response times for the various process line diameters as a function of length.

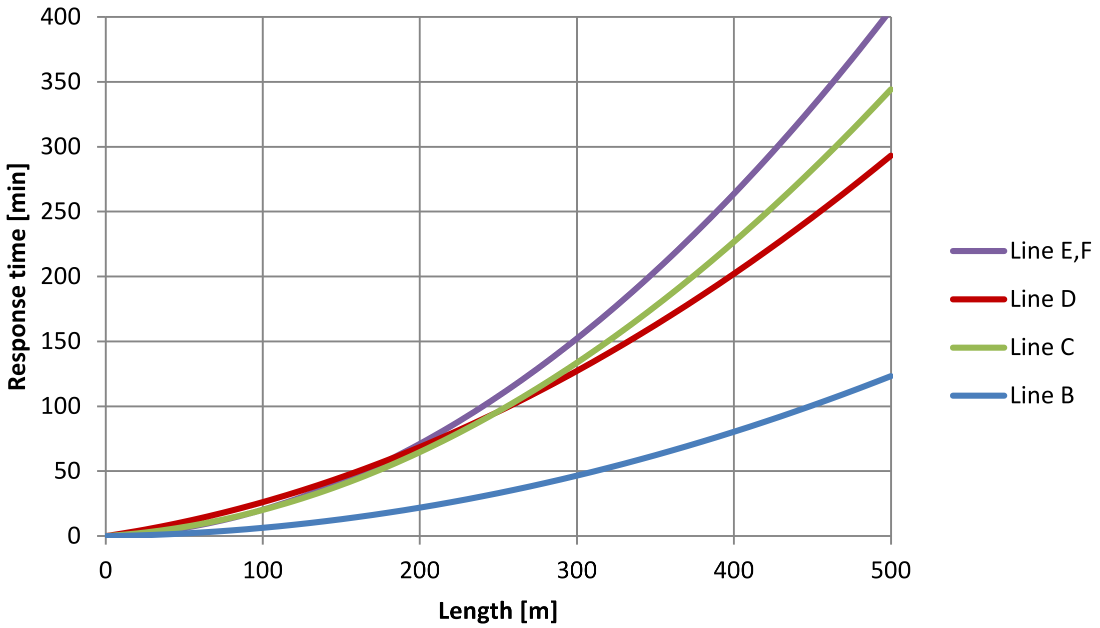

Figure 8 – Calculated response time as a function of length for the different process line diameters.

4.3.1 Line B measurement

A measurement was made on a segment of line B (inner diameter 0.267 m) with a length of 260 m. The signal rise time (dead time) was measured to be 35 seconds.

The expected response time t_r according to equation *(7)* is 2137 seconds or **36** minutes.

The measured response time was around **27** minutes (estimation because the measurement had to be interrupted for an urgent intervention elsewhere). The measured response time is 25% shorter than the calculated value.

4.3.2 Line D measurement

A measurement was made on a segment of line D (inner diameter 0.15 m) with a length of 260 m. The signal rise time was measured to be 180 seconds.

The expected response time t_r according to equation *(7)* is 6108 seconds or **102** minutes.

The measured response time was around **80** minutes (estimation because the measurement had to be interrupted for an urgent intervention elsewhere). The measured response time is 22% shorter than the calculated value.

4.3.3 Line F measurement

A measurement was made on a segment of line F (inner diameter 0.08 m) with a length of 420 m. The signal rise time was measured to be 300 seconds.

The expected response time t_r according to equation *(7)* is 17381 seconds or **290** minutes.

The measured response time was around **220** minutes, which is 24% shorter than the calculated value.

4.4 Tunnel leak statistics

Tables 1 to 3 below 3 give a summary of the leaks classified by location, origin, type. Figure 9 shows the leak size distribution. Appendix D gives a full overview with the relevant details for every leak.

Table 1 - Summary of identified and localised leaks per sub sector and per circuit.

	Line E (Ø80)	Line F (Ø80)	Line C (Ø100)	Line D (Ø150)	Line B (Ø267)	Vacuum envelope	**Total**
ss A (IR8L)	-	-	-	2	-	3	**5**
ss B		2	3	1	5	4	**15**
ss C*		1	1	-	-	1	**3**
ss C		-	2	1	3	-	**6**
ss D		1	1	-	2	1	**5**
ss E (mid-arc)		2	-	-	2	1	**5**
ss F		1	-	-	3	3	**7**
ss G		-	2	1	2	1	**6**
ss H		-	-	-	1	2	**3**
ss I (IR7R)	-	1#	-	-	-	4	**5**
Total	**0**	**8**	**9**	**5**	**18**	**20**	**60**

*) Part of ss C which was temporarily installed with a temporary end module for cryogenic tests.
#) leak either in circuit of line E or line F

Table 2 - Summary of identified and localised leaks by origin.

Origin of leak	Quantity	Examples
Leaks in tunnel welds	27	pinholes, cracks, lack of penetration, unfinished welds
Imported leaks	25	leaking welds, leaking compensators, leaking cryo-valve
Leaks caused by parallel tunnel activities	8	badly mounted instrumentation feedthrough, untight gyrolok connection, drilled hole in compensator
Total	**60**	

Table 3 - Summary of identified and localised leaks by type.

Type of leak	Quantity
Welds	48
Bellows	2
Drilled holes	3
Cefilac seals	3
Others and unknown	4
Total	**60**

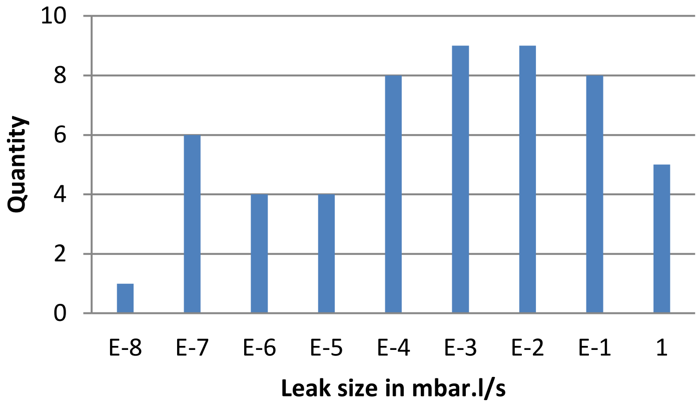

Figure 9 – Size distribution of detected and localised leaks.

4.5 Types of localised leaks

4.5.1 Weld defects

A total of 48 leaks due to weld defects such as pinholes and cracks have been encountered. These defects were sometimes visible by naked eye.

A number of welds made in UX65 and 110 were found to leak following interconnection welding in the tunnel. Such leaks may have slipped through the UX65 leak test unnoticed or they may have been caused by the tunnel interconnection welding process.

A few very large leaks were due to forgotten or incomplete weld repairs. This type of leak did not reoccur following the start of a systematic visual inspection of tunnel welds before the start of leak testing.

4.5.2 Leaking multiply bellows

On two line B multi-ply compensators, semi-virtual leaks with very long response times have been identified. In case of doubt, an accumulation test was performed with a He overpressure inside the process line and a plastic pocket enveloping the compensator.

Following an accumulation time (typically overnight), the He concentration inside the pocket as measured with a sniffer would confirm the presence of a leak.

4.5.3 Accidentally drilled holes in process line compensators

On three occasions a leak was identified in process line F during the global test with the vacuum envelope under vacuum. In all three cases, no leak was detected during the under vacuum tests of the process lines. The leaks only appeared during the global test of the process lines of the full sub-sector. Localisation of the leaks was complicated by the fact that all interconnects had been fully closed, including the vacuum envelope.

By pumping the leaking process line from both ends with two turbomolecular pumps, both backed by a leak detector, the amplitude of the leak signals as seen by both detectors gave an indication of the longitudinal position of the leak. Following opening of the vacuum envelope at the suspect interconnection, a drilled hole was found in the outer sleeve of the line F compensator.

The team in charge of closing the vacuum envelope interconnects, drilled a number of holes through the thermal shield in order to pop-rivet it in place. On three occasions, they apparently drilled not only though the thermal shield but also through the outer sleeve of the line F compensator (in one case the sleeve was actually pop-riveted to the thermal shield, see figure 10). This problem concerned line F in all three cases, because the two aluminium half shells of the thermal shield have their pop-riveted joint at the bottom position where line F is also located.

A subsequent modification in the interconnection closing procedure (no in-situ drilling allowed) made sure that such incidents did not happen anymore.

Figure 10 – Accidentally drilled and pop-riveted F line compensator.

4.5.4 Imported leaks in previously tested components

Although the TE-VSC vacuum test mandate only concerned the welds made in the tunnel, there have been several occasions were so-called imported leaks would have to be detected, localised and repaired before a conclusive test on the tunnel welds could be performed.

The most challenging example was the internal leak in line C of service module AA107 in sub-sector C which was only identified during the global test of the process lines. To avoid re-opening a large number of interconnects, a leak localisation system with a mobile inflatable plug was designed, built and successfully used [12].

5. Non-solved leaks and leaks identified after completion of installation

5.1 Leak in line B in sub-sector A or in the interaction region

During the pressure test of the process lines of sub-sectors A, B and C’ on 1 September 2005, a leak in process line B was identified. Comparison of the leak signals on the leak detectors at different positions indicated the leak to be in the interaction region (which shares its insulation vacuum with ss A). The leak size was measured at around 1E-4 mbar.l/s (at room temperature and with 1 bar abs of He inside line B).

A number of interconnections in the interaction region have been opened, but the leak has not yet been localised. Further investigation would require the opening of welded assemblies to allow access for further leak localisation.

The contribution of the leak to the equilibrium He pressure in the insulation vacuum under operating conditions (16 mbar at 4K) was estimated at 0.016*100*1E-4 mbar.l.s^{-1}/150 l.s^{-1} = 1E-6 mbar. In view of the required heavy mechanical intervention for further testing, it was decided to “use as is”. An additional ISO-K-100 pumping port has been installed on the

QRL vacuum envelope in the junction region which will allow to install additional pumping if necessary.

The tests so far have been documented [13] and localisation activities can continue if required.

5.2 Possible leak in envelope of sub-sector A

During the first two warm-ups of QRL sector 7-8, the vacuum pressure in the insulation vacuum of SS A has risen to >1 mbar and stalled its pumping group on the A/B bypass.

A number of non-conclusive investigations have been performed. They have been documented in NC 965042, together with a proposal for further investigation if required.

Conclusion

During reinstallation of the the QRL in sector 7-8, a total of 60 leaks have been identified, localised and repaired in the tunnel. 27 were leaking tunnel welds, 25 were imported leaks (e.g internal leak in service module AA107) and 8 leaks were caused by parallel tunnel activities (e.g. drilled holes in compensators).

The measured response times for under vacuum leak tests of the process lines were 20-25% shorter than the calculated values which is well within the error margins of the relevant parameters.

Two possible leaks remain, one in sub-sector A and one in the interaction region linked to ss A, for which the investigations so far have been documented and for which investigations will continue when required.

The QRL tests have provided valuable experience for the subsequent LHC magnet installation leak test activities (tooling, methodology).

References

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[13] Paper file kept in office 30-1-026.

Contractor:	HELIUM MASS SPECTROMETER LEAK TEST REPORT UNDER VACUUM METHOD	Job number: N°__________

QRL PE Part identifier.............................: LHCQRL______________________________

Leak test procedure (Ref. N°, Revision) ....: Butt weld inner lines, He spray

Volume to be tested ....: 35 (line F) to 400 (line B) dm^3

Pump type ....: Varian TM + Edwards 18 m3/h

Helium Mass Spectrometer type ....: Leybold PhoeniXL 300

C (Volumetric fraction of tracer gas) .. : 50 %

Leak test conditions

Line	R_F [*]	S_F [$]	qG [#]	qGm [&]
Line B butt weld				
Line C butt weld				
Line D butt weld				
Line F butt weld				
Line E butt weld				

Leak tightness requirements ≤ 1x10^{-9} (50% He) mbar l s^{-1}	Remarks:
Conformance.....: YES / NO	

Operator	Checked by	Approved by
Date..:	Date..:	Date..:
Name:	Name:	Name:

*) R_F = Residual He signal prior to He spray

$) S_F = Residual He signal after He spray

#) q_G = Leak evaluation (q_G = S_F - R_F)

&) q_{Gm} = Test sensitivity (50% He)

N. Kos
Revision 0
Date: 12.05.2005

English version

Contractor:	HELIUM MASS SPECTROMETER LEAK TEST REPORT UNDER VACUUM METHOD	Job number: N°__________

QRL PE Part identifier .... : LHCQRL______________________________

Leak test procedure (Ref. N°, Revision) .... : S rings on cryostat flanges, He spray

Volume to be tested .... : 1 dm^3

Helium Mass Spectrometer type .... : Leybold PhoeniXL 300

C (Volumetric fraction of tracer gas) .. : 50 %

Leak test conditions S ring LEFT side				Leak test conditions S ring RIGHT side			
R_F *	S_F $	qG #	qGm &	R_F *	S_F $	qG #	qGm &

Leak tightness requirements ≤ $1x10^{-9}$ (50% He) mbar l s^{-1}	**Remarks:**
Conformance.....: YES / NO	

Operator	Checked by	Approved by
Date..:	Date..:	Date..:
Name:	Name:	Name:

*) R_F = Residual He signal prior to He spray

$) S_F = Residual He signal after He spray

#) q_G = Leak evaluation (q_G = S_F - R_F)

&) q_{Gm} = Test sensitivity (50% He)

N. Kos
Revision 0
Date: 12.05.2005

English version

Contractor:	HELIUM MASS SPECTROMETER LEAK TEST REPORT UNDER VACUUM METHOD	Job number: N°__________

QRL Part identifier.................................. :	______________________________
Leak test procedure (Ref. N°, Revision) .... :	Compensator inner line, under vacuum method
Volume to be tested .... :	5 dm^3 (line E / F) to 50 dm^3 (line B)
Pump type .... :	C, E and F : Pumped with detector B and D : Varian TM + Edwards 18 m3/h
Helium Mass Spectrometer type .... :	Leybold PhoeniXL 300
C (Volumetric fraction of tracer gas) .. :	50 %

Leak test conditions

R_F *	S_F $	qG #	qGm &

Leak tightness requirements ≤ $1x10^{-9}$ (50% He) mbar l s^{-1}	Remarks:
Conformance.....: YES / NO	

Operator	Checked by	Approved by
Date..:	Date..:	Date..:
Name:	Name:	Name:

*) R_F = Residual He signal prior to He spray

$) S_F = Residual He signal after He spray

#) q_G = Leak evaluation (q_G = S_F - R_F)

&) q_{Gm} = Test sensitivity (50% He)

N. Kos
Revision 0.1
Date: 24.06.2005

English version

Details of leaks detected in the tunnel during reinstallation of QRL 7-8

Nr	ss*	Leak position	Circuit	Leak size [mbar.l/s]	Leak type	Detection method	Remarks
1	A	EA 001 (6L8)	D		Ø8 mm gyrolok	He spray	untight gyrolok connections of PP/TT sensor
2	A	QQICB.B4L8	D	>1	weld	visual inspection	unfinished weld, 2 cm missing
3	A	QQICB.B6L8	envelope	1E-1	weld	He spray	
4	A	QQIAB.6L8	envelope	5E-3	weld	He spray	
5	A	QQIOB.C4L8	envelope	1E-3	weld	He spray	
6	B	QQIAA.9L8	B	4E-4	weld	clam shell/He spray	leak identified with clam shell and confirmed with under vacuum test
7	B	QQIAA.A14L8	C	≥2E-8	weld	clam shell	
8	B	QQICA.B13L8	F		weld	He spray/He pocket	
9	B	QQIOA.B13L8	C	>1E-4	weld	He pocket	
10	B	QQIOA.B12L8	B	>1E-7	weld	He spray	2 repairs necessary
11	B	QQIAA.A10L8	B	>1E-1	imported weld	He spray	leak on weld made in UX65
12	B	QQIOA.B12L8	C	>1E-7	imported weld	He spray	2 repairs necessary
13	B	QQIOA.C11L8	B	>1E-5	weld	He spray	leak on left hand side (towards IR7)
14	B	QQIOA.C11L8	B	>1E-4	weld	He spray	leak on right hand side (towards IR8)
15	B	QQIOA.A12L8	D	>1E-7	weld	He spray	
16	B	QQICA.A14L8	F	>1E-1	weld	He spray	
17	B	QQIOA.A16L8	envelope	>1E-2	imported weld	He spray	
18	B	QQIOA.8L8	envelope	1E-3	weld	He spray	
19	B	QQIOA.C15L8	envelope		imported weld	He spray	leak on weld made in 110
20	B	QQIOA.A9L8	envelope		weld	He spray	
21	C’ #	QQIOA.C16L8	C	>1E-1	weld	clam shell	
22	C’	QQIOA.A17L8	envelope	1	weld	He spray	
23	C’	17L8	F	3E-4	unknown	global test	leak disappeared with removal of temporary C’ components
24	C	QQIOA.C19L8	D	1E-1	imported weld	He spray	pin hole in weld made in 110
25	C	QQIOA.A23L8	B	1E-2	imported weld	He spray	leak on weld made in 110
26	C	QQIOA.C22L8	B	>1E-3	imported weld	He spray	leak on weld made in UX65
27	C	QQIAA.24L8	B	>1E-6	imported weld	He spray	leak on weld made in UX65
28	C	AA 107 (22L8)	C	1E-5	imported weld	inflatable plug	leak inside service module
29	C	QQICA.21L8	C	5E-2	Imported weld	clam shell	leak following exchange of compensator, maybe due to grinding

*) sub sector
#) part of ss C which was temporarily installed with a temporary end module for cryogenic tests.

Nr	ss*	Leak position	Circuit	Leak size [mbar.l/s]	Leak type	Detection method	Remarks
30	D	QQIOA.C25L8	B	≥1E-4	weld	He spray	
31	D	QQIOA.C30L8	F	1E-1	imported weld	He spray	leaking weld made in 110
32	D	QQIOA.C28L8	C	≥2E-4	weld	He spray	weld locally ground and not rewelded
33	D	QQIOA.A27L8	B	≥6E-7	weld	He spray	weld locally ground and not rewelded
34	D	LA 139(31L8)	envelope	8E-6	imported weld	He pocket	leak in helical cryostat weld, partially plugged by the paint
35	E	QQICA.34L8	B	>3E-6	bellows	He pocket	semi-virtual leak in multiply bellows (signal rise time 2.5 min)
36	E	AA 110 (34L8)	B	>1E-7	cefilac seal	He spray	DN50 seal instrumentation feedthrough
37	E	QQICA.34R7	F	>1	drilled hole	visually	drilled hole in compensator
38	E	QQICA.34L8	F	>1	drilled hole	inflatable plug	drilled hole in compensator
39	E	AA 110 (34L8)	envelope	1E-5	imported weld	He spray	weld on the base of DN100 overpressure valve
40	F	QQICA.29R7	B	≥1E-2	weld	He spray	2 repairs necessary
41	F	QQIOA.A25R7	B	1E-1	weld	He spray	2 repairs necessary
42	F	AA 101 (29R7)	B		cefilac seal	He spray	DN50 seal instrumentation feedthrough
43	F	QQIOA.C26R7	envelope	5E-2	imported weld	He spray	weld not tested in UX65
44	F	QQICA.27R7	envelope	5E-2	imported weld	He spray	weld not tested in UX65
45	F	QQIOA.B28R7	envelope	1E-3	imported weld	He spray	compensator roll weld, 2 repairs necessary
46	F	QQICA.28R7	F	2E-2	drilled hole	global test	drilled hole in compensator
47	G	QQICA.21R7	C	>1	pinhole weld	bubble spray	
48	G	AA 108 (21R7)	D	1E-2		He spray	cryogenic valve CV943
49	G	QQQIOA.B17R7	C	>1E-1	weld	He spray	
50	G	AA 102 (17R7)	B	1E-4	cefilac seal	He spray	DN50 seal instrumentation feedthrough
51	G	QQICA.21R7	B	>3E-6	bellows	He pocket	semi-virtual leak in multiply bellows (signal rise time 2 min)
52	G	QQIOA.C23R7	envelope	1E-5	imported weld	He spray	leaking weld made in 110
53	H	QQICA.16R7	B	1E-3	(imported?) weld	He spray	imported or tunnel weld
54	H	QQIOA.C13R7	envelope	1E-2	imported weld	He spray	leaking weld made in UX65
55	H	QQIOA.A11R7	envelope	1E-7	imported weld	He spray	compensator roll weld
56	I	IA 001 (6R7)	E or F		instrum. f.through	He spray	wrongly mounted
57	I	QQICC.6R7	envelope	1E-3	weld	He spray	
58	I	QQICC.6R7	envelope	5E-4	imported weld	He spray	compensator roll weld
59	I	QQIAF.7R7	envelope	1E-3	weld	He spray	right hand side weld
60	I	QQIAF.7R7	envelope	1E-3	weld	He spray	left hand side weld