

ORBITAL WELDING OF QRL LINE IN CONFINED ENVIRONMENT

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INTRODUCTION

This document relates the installation of QRL line (cryogenic line) for the LHC project (Large Hadron Collider). This line has been installed on CERN site (European Organization for Nuclear Research).

The QRL line supplies helium at 1.8 K to LHC magnets.

AIR LIQUIDE DTA was responsible for:

- design,
- manufacturing of elements : manual welding in workshop
- and installation of QRL lines : by orbital welding

This line has been installed in a circular underground tunnel of 27 km: the ring yields a curve and introduces specific requirements for installation and orbital welding preparation.

This cryogenic line has been manufactured in reference to French code CODAP, cat B, $z = 0.85$. Furthermore additional requirements were defined by CERN

The cryogenic line was divided by 8 sectors. With an approximately length of 3 km for each.

For this project more than 15 000 orbital welds and 600 manual welds have been realized to connect inner pipes.

PRE-MANUFACTURING OF ELEMENTS

Several elements have been installed on QRL line. These elements were manufactured in several workshops and integrated in CERN tunnel. To respect cryogenic requirements, four main parts were defined:

- Inner pipes in contact with cryogenic fluid. With different cryogenic temperatures: 1.8 to 80 K, with diameters between 84 to 273 mm.

- insulation + thermal screen
- outer envelope : 610 to 650 mm
- vacuum between inner pipes and outer envelope

For this cryogenic line a specific design was applied.

This cryogenic line is made with different elements:

- 1900 pipe elements: which are straight elements. (ϕ 610 & ϕ 650 mm - $L = 11,5$ m / 6 m).
- 240 fix point to guarantee mechanical stability and vacuum barrier: the line is divided in vacuum sectors of 400 m. At each end a tight barrier was installed.
- 310 Service modules: these elements realize the connexion with magnets of LHC machine
- Several specific elements: 50 elbows and steps to follow the tunnel design which is not linear.
- Due to thermal dilatation internal compensators have been welded

The following scheme and picture show an end of pipe element:

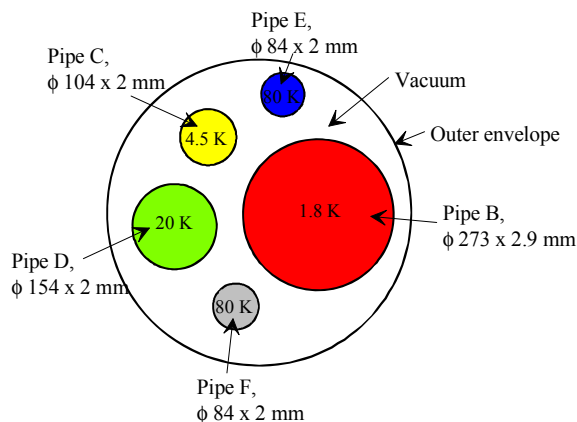


Figure 1: end of pipe element before welding

To connect these elements: more than 3200 junctions have been welded (one junction = welding of inner pipes + external pipes). For each junction we have welded:

- 4 or 5 inner pipes, with butt weld preparation
- 2 external welds, with lap joint preparation

Inner pipes have been welded by orbital welding. External pipes have been welded manually.

For this project AIR LIQUIDE has welded:

- for inner pipes: more than 15 000 orbital welds with a cumulated length of 6 km.
 - for external welds: more than 12 km of manual weld
- This article is about orbital welding of inner pipes.

WELDING

Welding configuration

For inner pipes AIR LIQUIDE has chosen 1.4306 stainless steel and defined two welding configurations:

- When backing gas was possible: butt weld, with machining of face.
- When backing gas did not guarantee a sufficient protection: butt weld with permanent backing support.

We present the main properties of pipes in following table:

Table 1: size of pipes

	Pipe B	Pipe C	Pipe D	Pipe E and F
Diameter (mm)	273	104	154	84
Thickness (mm)	2.9	2	2	2

As these pipes were to be welded, pipes have been provided with specific requirements. We specified requirements for:

- Chemical composition to avoid “Marangoni effect” during welding. These requirements were in accordance with IIW recommendations (International Institute of Welding)
- Specific tolerances for diameter and thickness

Parameters

For C / D / E and F pipes, we welded with same parameters.

Specific parameters have been used to weld B pipe.

Main parameters were as follow:

- Single pass welding
- Welding gas: ARCAL 15, mixture Ar + H₂. The same welding gas has been used for 2 and 2.9 mm. In this case 2.9 mm thickness leads the choice.
- backing gas: ARCAL 1 (pure argon)
- welding with pulsated current
- welding with arc voltage control
- welding with filler metal

Depending of torch position we adjusted welding parameters: parameters per sectors.

The following table presents the main parameters.

Table 2: main parameters

	Average amperage (A)	Voltage (V)	Speed (mm/min)
2 mm of thickness	43	11.3	75
2.9 mm of thickness	52	10.7	60

To guarantee the results during welding, we authorize a maximum gap of 0.5 mm

Orbital welding machine

We have welded with an open head. Due to welding configuration specific equipment has been designed, this equipment has been manufactured by ORBITAL Company. For CERN project we had specific requirements.

The minimum radial clearance around pipes was 60 mm, with an axial clearance of 150 mm.

Air flow in CERN tunnel can disturb welding operation. We have installed protection to protect welding area.

Due to limited access we decided to control the welding cycle with a camera. The main characteristics are as follows:

- same head to weld 84 to 273 mm, modification of configuration required less than 5 minutes
- head rotation was realized with a chain + guide
- a water cooled head
- reel of filler metal integrated on head
- camera to adjust the lateral position of electrode
- motors for rotation and to adjust :
- lateral position
- arc voltage control of arc

The following figure shows the head on a B pipe:

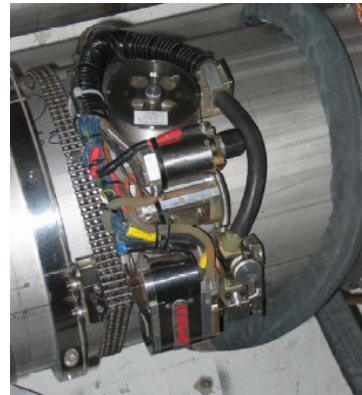


Figure 2: view of welding machine

Referring to manual welding time, orbital machine has reduced significantly duration of operation. To weld a 4 pipes junction:

- manual welding requires : at least 4 hours
- orbital welding requires : 1.5 hours

Alignment and purging system

When it was possible we have welded with CENTRATOR machine. Expansion of clamps is mechanised and this equipment realizes:

- purging with inert gas
- alignment before welding.



Figure 3: view of welding machine

These tools avoid tack welding and limit purging time. Unfortunately the CENTRATOR machine requires axial access to introduce it. When we could not use them, we used expendable balloon. In this case it was necessary to tack weld and the purging time was longer.

NON DESTRUCTIVE EXAMINATION

Visual examination

Acceptance criteria for X-ray and visual examination were in accordance with EN 25817, class B. Welds that did not meet these criteria have been repaired.

According to requirements we have realized inspection from torch side and root side. For root side inspection, welds have been inspected and recorded on digital support. Each weld has been visually inspected.

The level of unacceptable welds is defined in table 3.

X-ray inspection

CERN specifications define different level of examination:

- For manual welding we had to inspect 100 % of welds
- For orbital welding: random examination was required, with at least 10 % of examination.

Helium leak test

The tightness of each weld has been tested. After welding we have tested with:

- ΔP of 1 bar, pressure inside and local vacuum outside. Local vacuum realized with a specific jig : local chamber connected to spectrometer
- Individual acceptance criterion of $2 \cdot 10^{-9}$ mbar.l/s

Results

The following table presents results of X-ray, visual examination and tightness test for butt welds without backing support.

Table 3: NDE results of orbital butt welds

	Not accepted by visual examination (1)	Not accepted by X-ray (2)	Not accepted by helium leak test (3)
2 mm thickness	0.3 %	0.78 %	(3)
2.9 mm thickness	2.18 %	2.82 %	(3)

(1): results of full examination

(2): results of random examination

(3): Only one leak has been detected for more than 15 000 orbital welds inspected.

Results of weld with backing support are a little less good. Table 4 proposes a distribution of defect detected by X-ray.

Note: the total of defects can be higher than 100% due to cumulated defects. As we can see gas pores is the main defect.

Table 4: defect distribution (detected by NDE)

	Gas pore	Sugaring - root porosity	Lack of penetration	Others
Orbital welding	46 %	31 %	17 %	6 %
Manual welding	59 %	33 %	11 %	11 %
Orbital weld with support	87 %	8 %		5 %
Manual weld with support	63 %	30 %		14 %

CONCLUSIONS

This industrial application on more than 15.000 welds is a rich lesson.

We must take into account several comments and conclusions. To benefit of orbital advantage it is necessary:

To train teams “pipe fitters” - complementary “welders” to obtain results of quality

A permanent maintenance is necessary

The main advantages are as follows:

The welding time is reduced with orbital welding. Approximately 1.5 hours to orbital weld a junction and more than 4 hours manually

Choice of the orbital technology TIG which made it possible to carry out the large majority of welds, without having resorts to highly specialized operators.

This choice allowed, after negotiation with the customer, to reduce radio operator controls on orbital welding. Whereas manual welds were to be inspected to 100%.

This reduction contributed to the manufacturing lead time, because X-ray in the tunnel stopped other works and displacements

Level of repair is low, especially for pipes with 2 mm wall thickness.

With this welding configuration and for 2.9 mm wall thickness we consider that single pass is an industrial upper limit. For thicker pipe an other technology should be proposed

Choice of the CENTRATOR machine is judicious : the double function “purgings - positioning” is very efficient.