Beampipes for Gravitational Wave Telescopes 2023

WP2: Manufacturing and welding options

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27.03.2023

Content

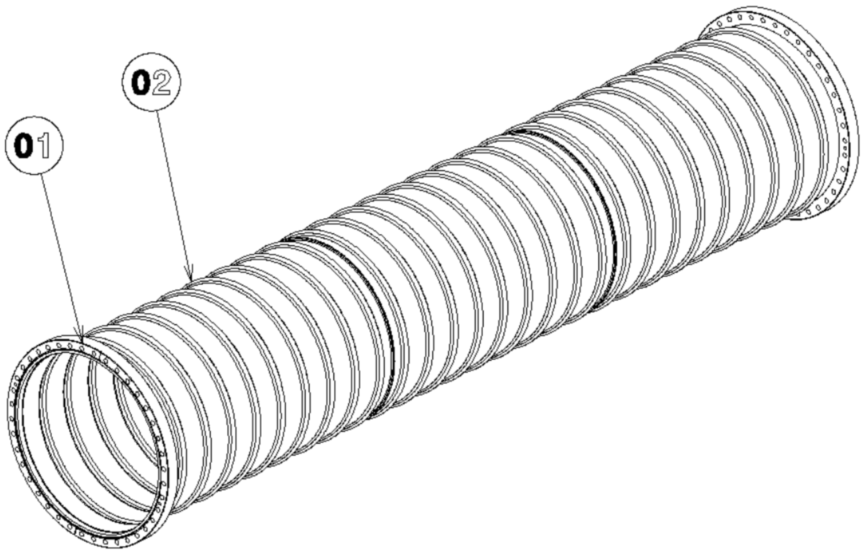
Beampipes:

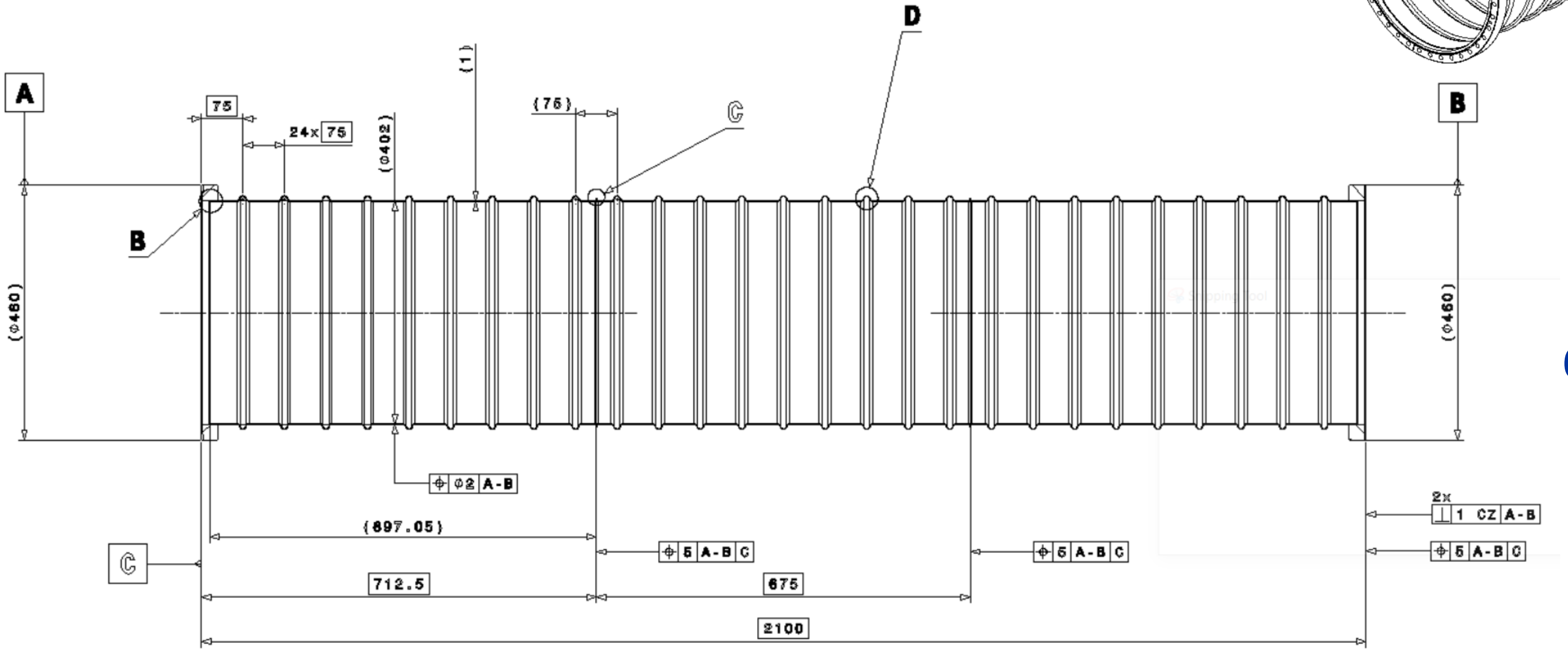
- Manufacturing of the pre-prototypes (forming and welding)
- Repair strategy
- Space requirements for in-situ assembly
- Next steps

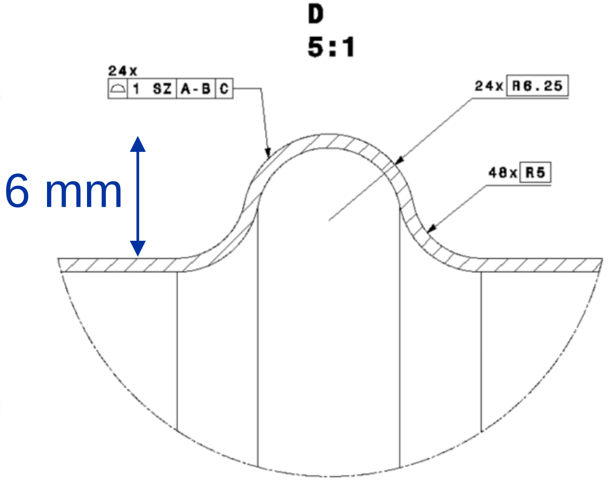
Design of the pre-prototypes

Corrugated pipe with thin wall thickness (in the order of 1.3 mm)

- Three segments of 675 mm, total length of 2.1 m
- Internal diameter: 402 mm



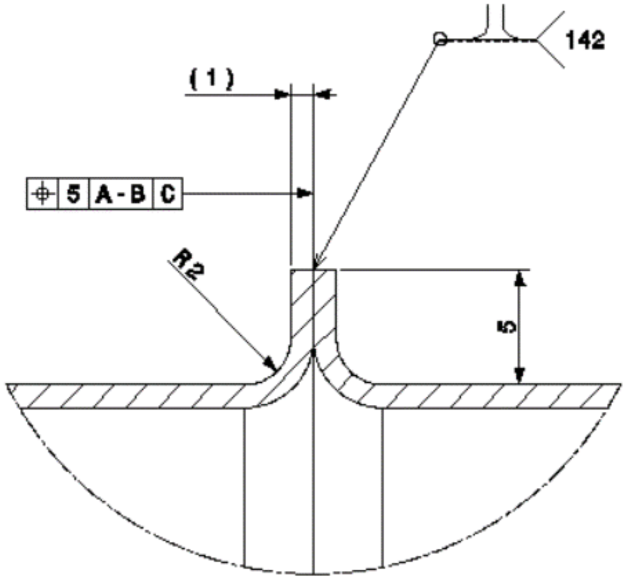


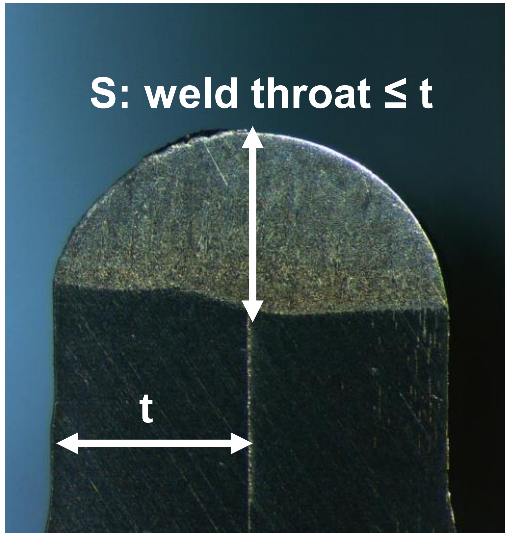


Design of the pre-prototypes

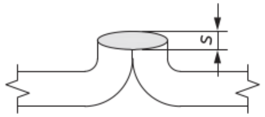
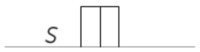
Joint design for segments assembly: “lips” type

- Main benefits:
  - No baking gas required
  - No filler metal required
  - “Easy” adjustment of parts to be welded (use of positioning and clamping tool)
  - Possibility to cut & reweld
  - Less risk of pollution inside the chamber when cutting
- Limitations:
  - Control of the weld quality: only visual inspection possible
  - Volume trapped between lips: potential outgassing (virtual leaks) & liquid retention (pollution)
- Targeted weld throat: equal to base material thickness (t)





ISO 2553: Symbolic representation on drawings -Welded joints

No.	Weld type	Illustration	Symbol [a]
7.2	Edge (flanged butt)		

Base materials considered

Benchmark study of:

- Austenitic stainless steel: **AISI 304L → benchmark**
- Ferritic stainless steel: **AISI 430**
- Structural mild steel: **S315MC**

	C	Mn	P	S	Si	Cr	Ni	N	Cu	Nb+Ti+V	Fe
AISI 304L	< 0.03	≤ 2.0	≤ 0.030*	≤ 0.015*	≤ 1.0	17.0-20.0*	10.0-12.5	0.1	-	-	balance
AISI 430	< 0.12 0.044	≤ 1.0 0.32	≤ 0.040 0.027	≤ 0.030 0.001	≤ 1.0 0.370	16.0-18.0 16.05	0.75 0.22	- 0.042	- 0.070	- -	balance
S315MC	≤ 0.12 0.042	≤ 1.3 0.45	≤ 0.025 0.0055	≤ 0.020 0.0023	≤ 0.5 0.027	- 0.05	- 0.07	- 0.007	≤ 0.22 0.17	≤ 0.22 0.0121	balance

	Rm (MPa)	Rp_{02} (MPa)	A (%)	HB
AISI 304L	≥ 520*	≥ 220*	≥ 45*	≤ 180*
AISI 430	≥ 450 482	≥ 205 349	≥ 22 30	≤ 183 140
S315MC (AISI 1392)	390-510 425	≥ 315 391	≥ 20 28	- 131

*CERN requirements

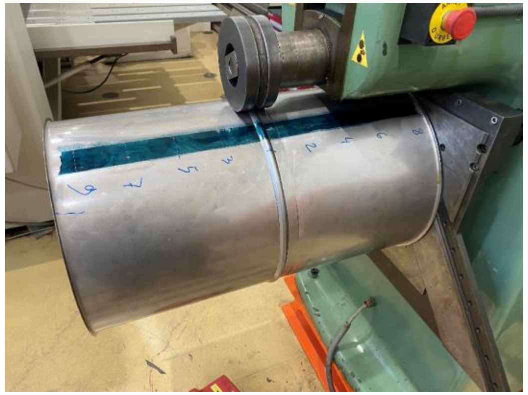
ASTM A240 for stainless steel grades and EN 10149-2 for mild steel

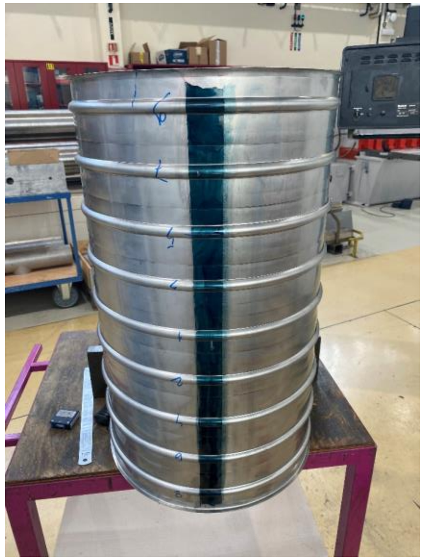
Courtesy of Ana Teresa Perez Fontenla

Fabrications steps

1. Fabrication of three segments of 675 mm length:
   - Fabrication of pipes: sheet rolling & mechanized TIG longitudinal welding
   - Forming of the corrugations & the “lips” using a swaging machine
   - Non destructive control: visual & X-ray
   - Degreasing


Longitudinal TIG Seam Welders

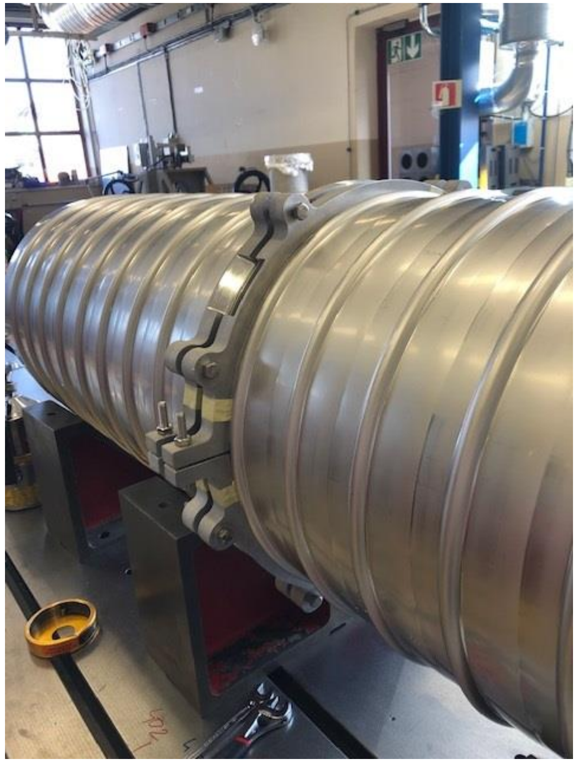


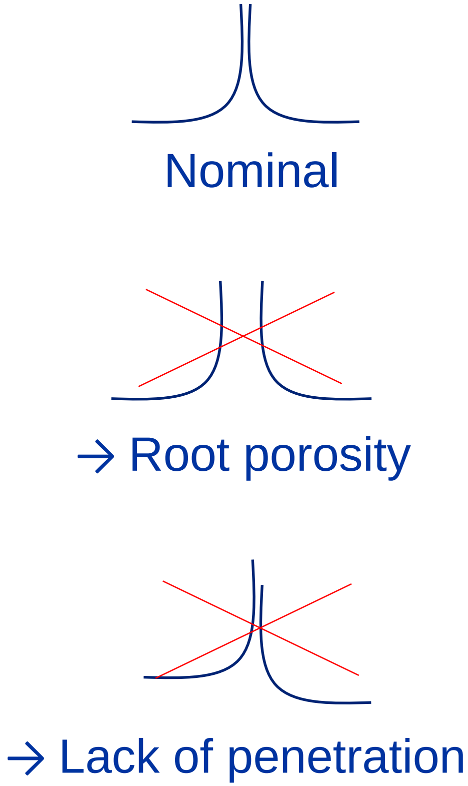


Swaging machine

Fabrications steps

2. Butt welding of the segments lips:
   - TIG manual welding of the segments using a positioning & clamping tool
   - Visual inspection





Dedicated clamping tool required to ensure close contact between lips (zero gap) with proper alignment

Preliminary results (1/3)

Austenitic stainless steel: AISI 304L
- Good weldability
- Good formability

A vacuum firing (950 °C – 2h) has been applied to the 304L chamber to be in the best possible conditions for UHV application.

304L pre-prototype will be the reference in our comparative study with ferritic steels and austenitic SS.

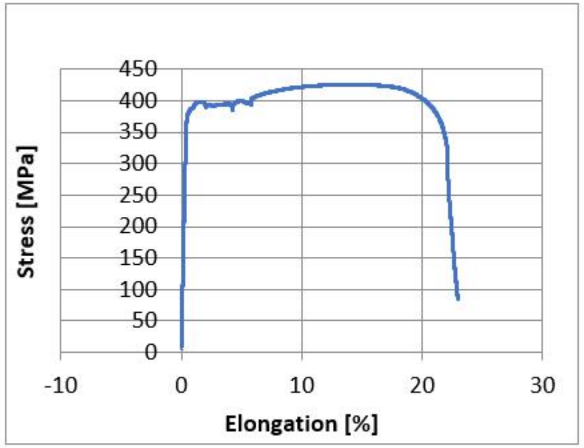
→ 304L Pre-prototype available for UHV tests

Preliminary results (2/3)

Structural mild steel: S315MC
- Good weldability
- Good formability

Tensile tests: failure occurred in the base material in a ductile manner

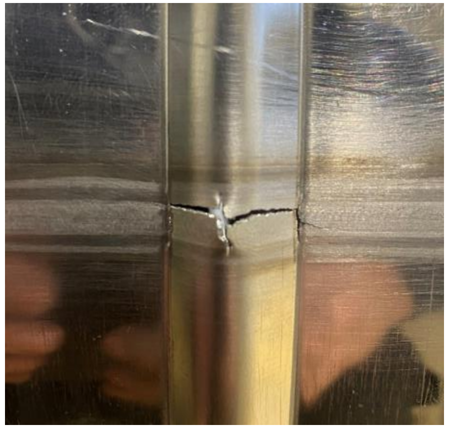
	Base material	Weld
Rp 0.2 (MPa)	390.6	390
Rm (MPa)	425.3	428
A%	27.5	22.5



→ 3 segments available, final welding to be done

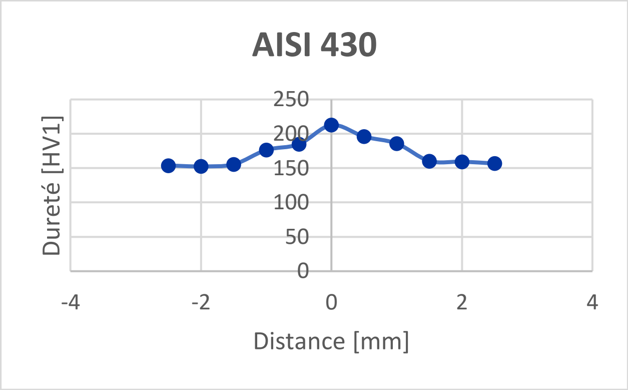
Courtesy of Ana Teresa Perez Fontenla

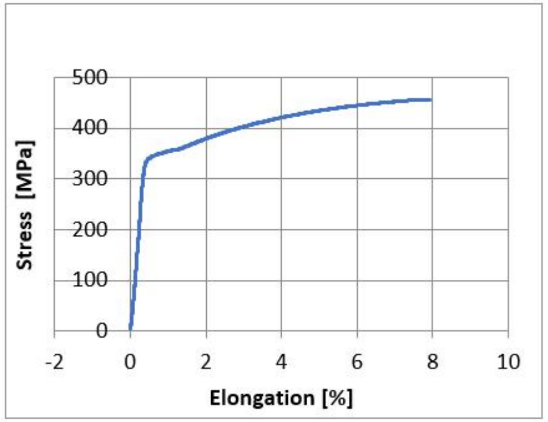
Preliminary results (3/3)



Ferritic stainless steel: AISI 430

- Weldable but sensitive to grain growth & martensite transformation
- Rupture in the weld induced by forming operation
- Optimisation of welding parameters to be done:
  - Limit heat input (change of process)
  - Use filler metal (may not be applicable for series production)
  - Adjust base material composition





Tensile tests:
failure occurred in the weld with a brittle failure mode

	Base material	Weld
Rp 0.2 (MPa)	334	330
Rm (MPa)	466	455
A%	31.9	**7.9**

Peak of hardness in the weld **212 HV**, 153 HV for the base material

Courtesy of Ana Teresa Perez Fontenla

Weld quality (1/2)

Length of welds to be performed for series production:

- Longitudinal welds: **minimum 120 km**
- Circular welds (8000 circular welds if segments of 15 m): **28 km**
- Quality level for weld imperfections required: Stringent (level B according to ISO 5817)

How can we ensure weld quality with high reproducibility of results?

- Use a high quality **mechanized welding process**
- Ensure a perfect and constant joint preparation

Check quality online:

- Register welding parameters
- Implement synchronous volumetric quality check when feasible (phased array ultrasonic testing for longitudinal welds)

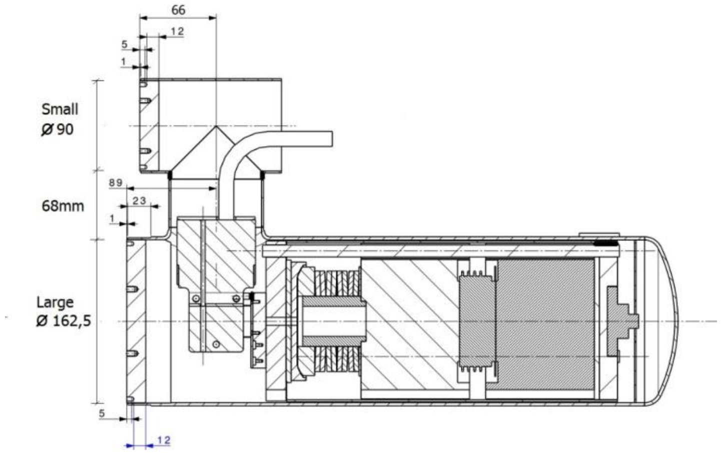
For the “lips” welds, volumetric quality check is not applicable

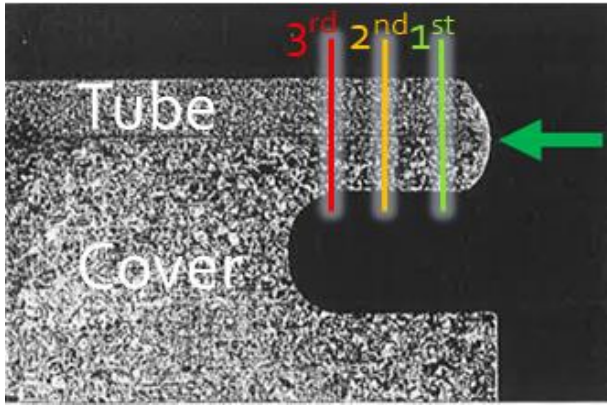
- Visual inspection is efficient for main defects detection
- Witness samples can be implemented for regular destructive examinations during production

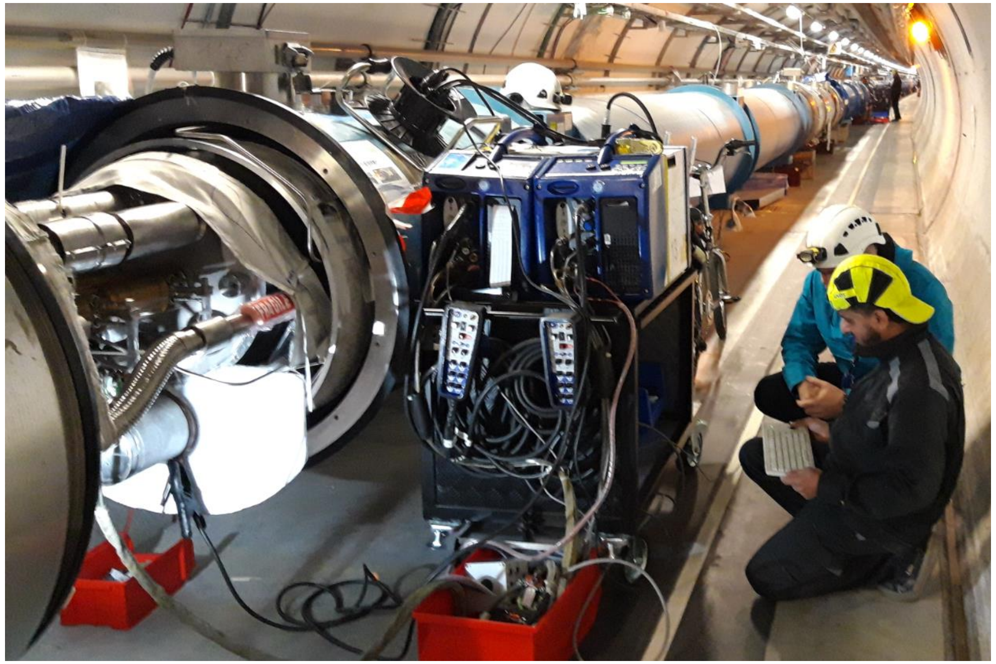
→ Good experience at CERN with “lips” welds; the few leaks detected were linked to hot cracking induced by accidental copper pollution in the weld

Weld quality: our experience at CERN (2/2)

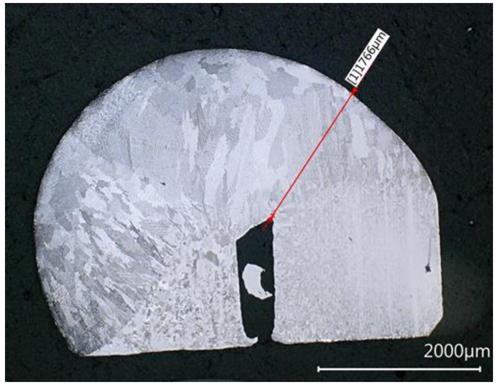
Diode-boxes dipoles consolidated during LS2 (2019-2020)
→ 2464 “lips” welds (~1000 m) without any leak





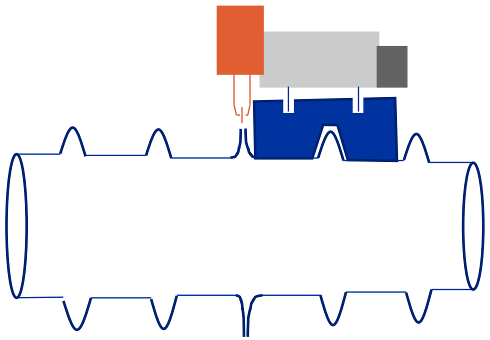


Visual Inspection using videoscope



Witness samples

Examples of mechanized welding machines

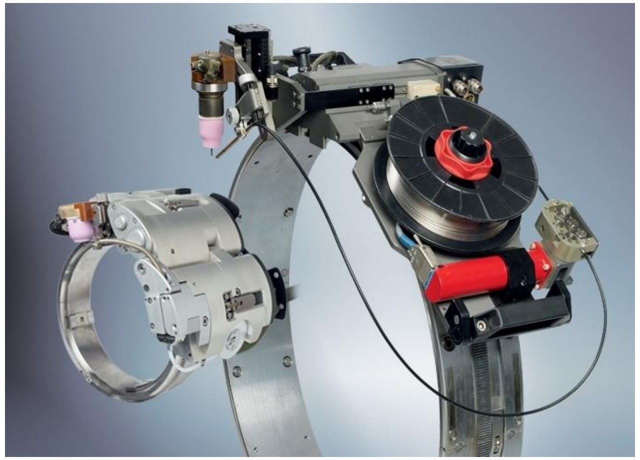


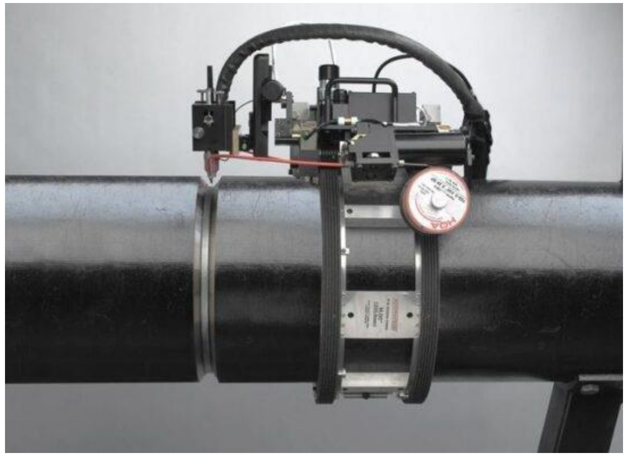
- Track ring to guide the welding heads

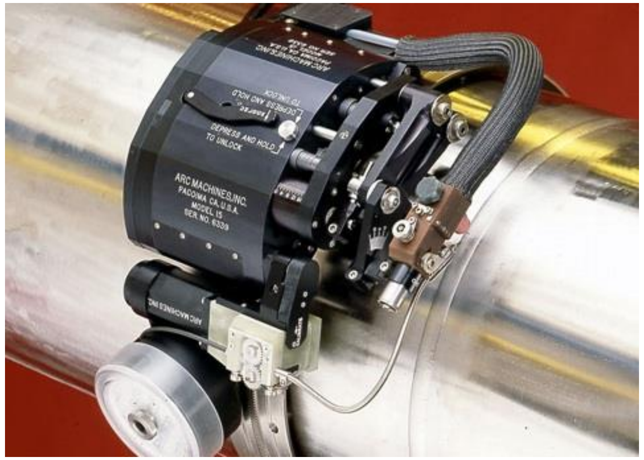
- Seam tracking (camera, sensor) can help to ensure proper alignment of the welding head w.r.t. the joint

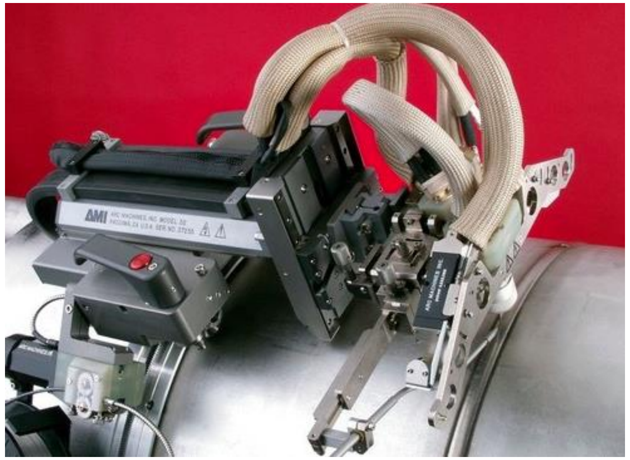
Laser seam tracking

Track ring

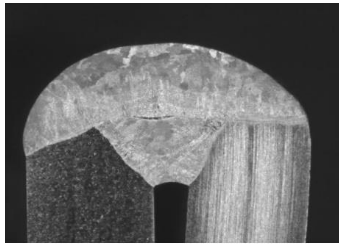








Non conformity of a "lips" weld



Local repair of a "lips" weld**:** manual repair (removal of the defect and remelting with or without filler metal)

Replacement of a damaged pipe

Use of an **orbital cutting machine**

- Procedure shall be optimised to minimize the reduction of "lips" height after cutting (TBD numbers of welding & cutting sequences required)

- Adjacent pipes shall be movable to allow removal of the defective pipe and installation of the new one with high precision positioning to reach the nominal configuration required for "lips" welding (zero gap).

Example of light and compact orbital milling machine developed at CERN for pipe cutting

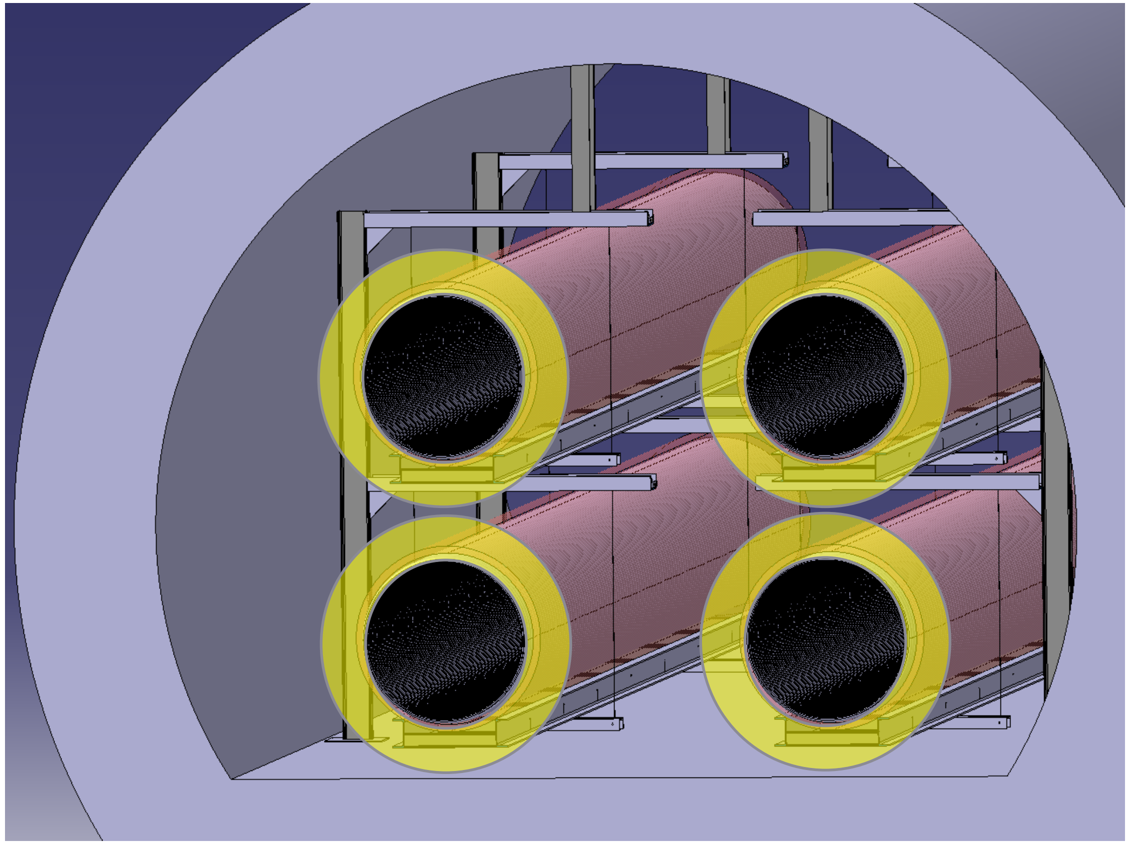
Space requirements for in-situ assembly

Free space required around joints to be welded. Shall be sufficient for:

- Mechanized welding & cutting machines installation & operation

- Technicians intervention
  - Visual inspections
  - Manual repairs
  - Installation of insulation
  - …

As first estimate
  - **400 mm** free space for machines could be sufficient
  - **500 mm** for technicians interventions would be recommended

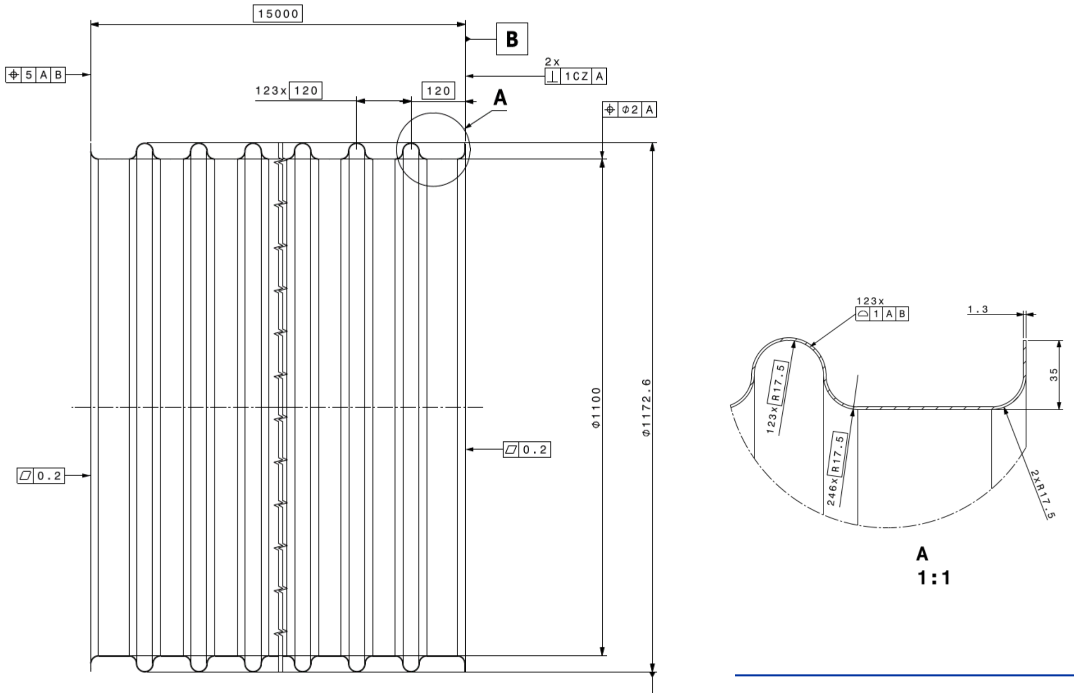


Next steps

1. Continue the development with **ferritic SS** for pre-prototypes
   - Development of new welding parameters on going

2. Fabrication of the **pilot sector** (foreseen in 2024)

   Objective is to manufacture two chambers of 50 m length, 1.1 m diameter ideally based on long segments of 15 m length
   - See if industrial existing solutions can (easily) be **adapted for UHV application**. May require a significant time for weld quality improvement
   - Alternative for pilot sector could be the manufacturing of “short segments” (in the order of 1.5 m length)
     - technology already available from bellows manufacturers
     - could also be produced at CERN



Pilot sector conceptual model
See L. Scibile talk

Summary

Three pre-prototypes in fabrication

- Austenitic stainless steel: welding & forming operation qualified, chamber ready to be tested
- Structural mild steel: welding & forming operation qualified, final assembly on going
- Ferritic stainless steel: welds quality shall be improved to withstand forming operations

Next step

- Discussions to be launched with industrial partners specialised in large corrugated chambers manufacturing to see if their standard process can be improved to satisfy the UHV requirements (base material and weld quality)

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