CRITICAL DESIGN REVIEW FOR THE WELDS OF PORT TUBES ON MONOLITH VESSEL

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Consorcio ESS-BILBAO, AVS and CADINOX

March 15^{th}*, 2021*

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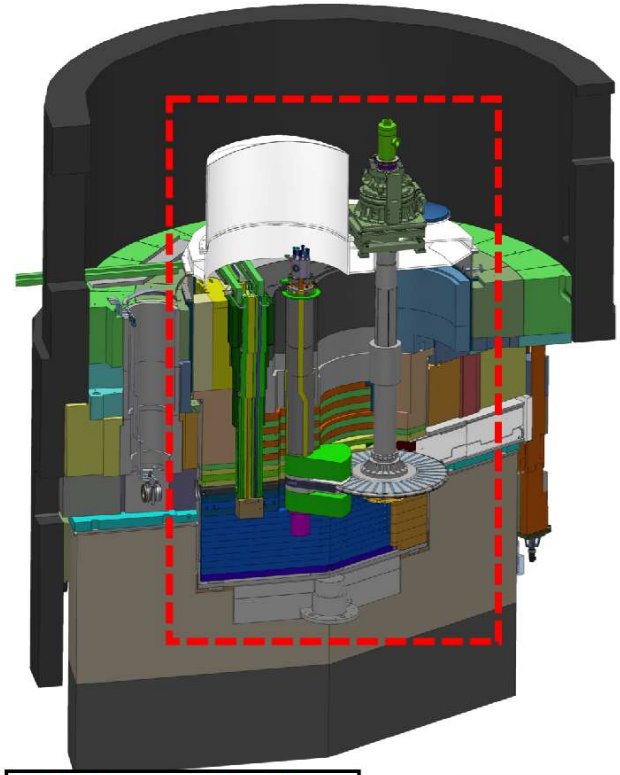
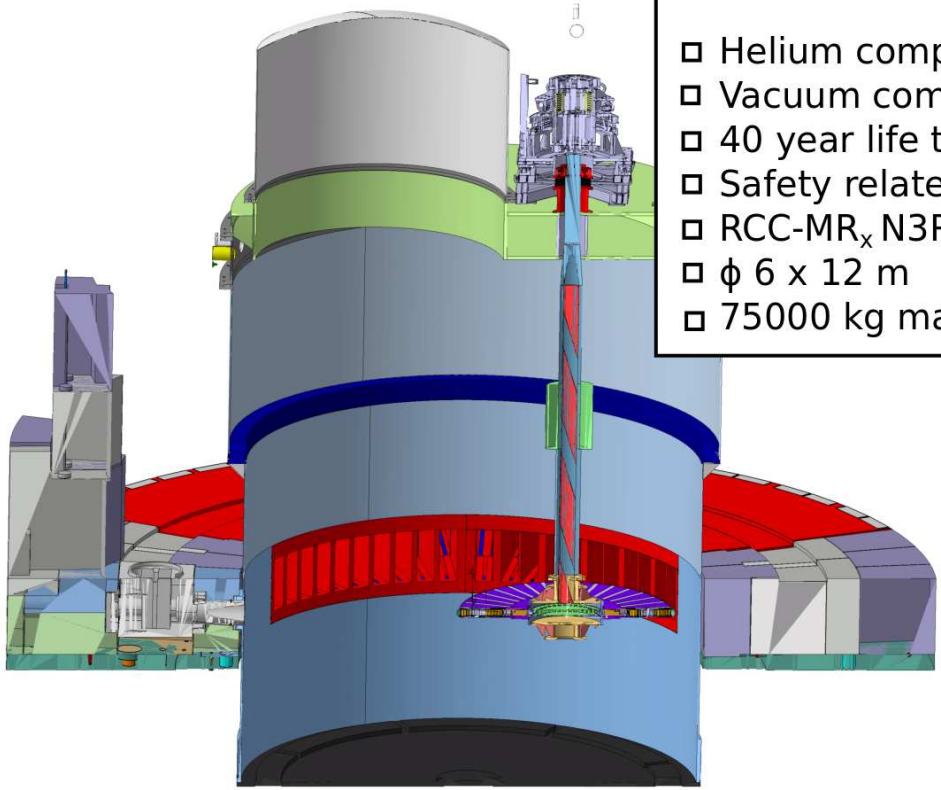
Monolith Vessel

ESS Monoltih Vessel on ESS target station



ESS Target Station



Monolith Vessel

Monoltih Vessel

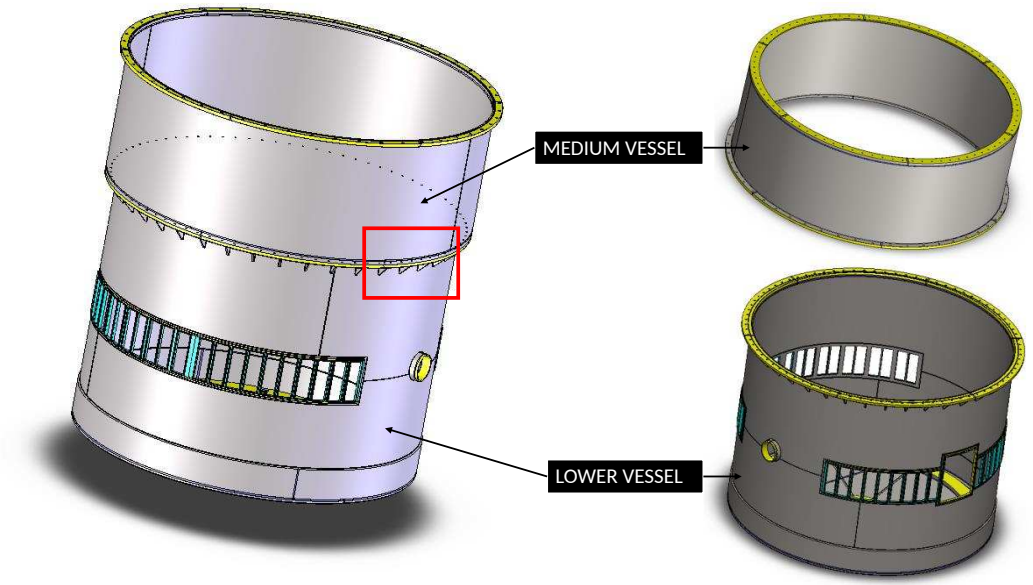
- Helium compatible
- Vacuum compatible
- 40 year life time
- Safety related equipment
- RCC-MR_x N3Rx
- ϕ 6 x 12 m
- 75000 kg mass

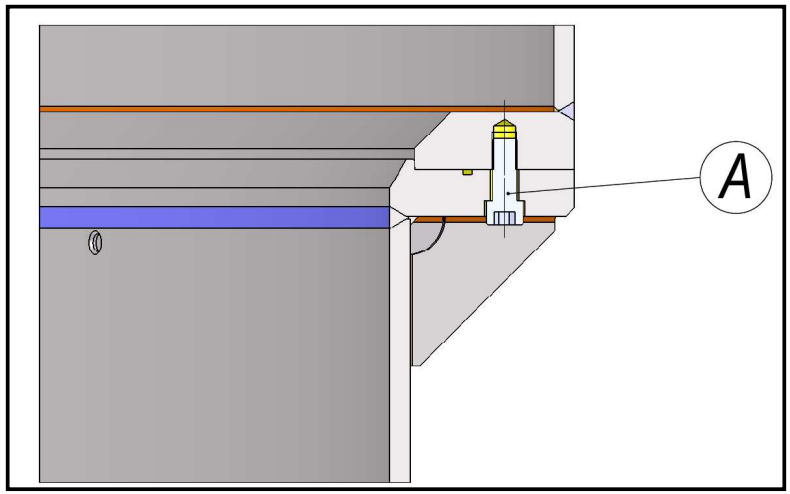
Redesign work

Contract awarded to AVS+CADINOX

On September 2018, the manufacturing contract was awarded to AVS+CADINOX. The new manufacturing team adapted the manufacturing plan to his technical capacities and split the vessel in two sections connected in a flange.

CADINOX vertical lathe. Maximum hight $\sim$ 3 m





Bolted connection
+ sealing weld on site

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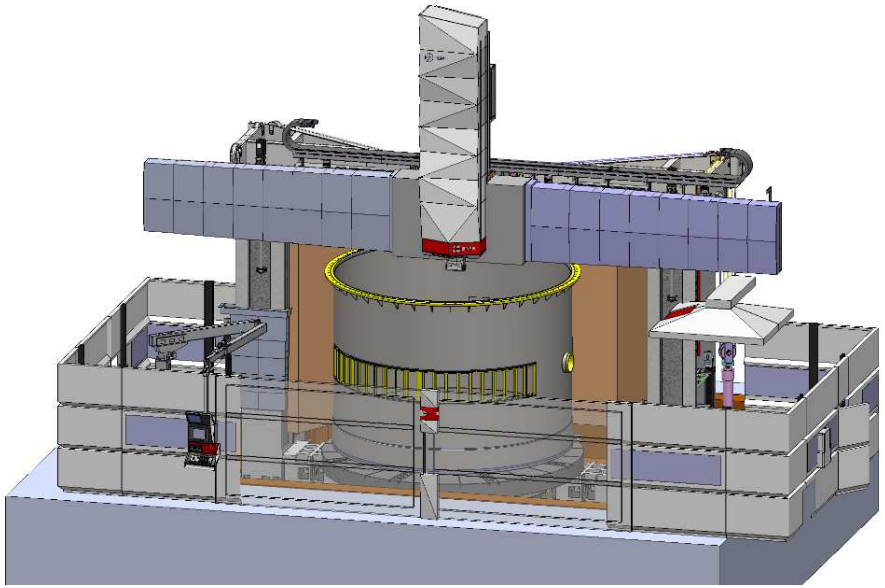
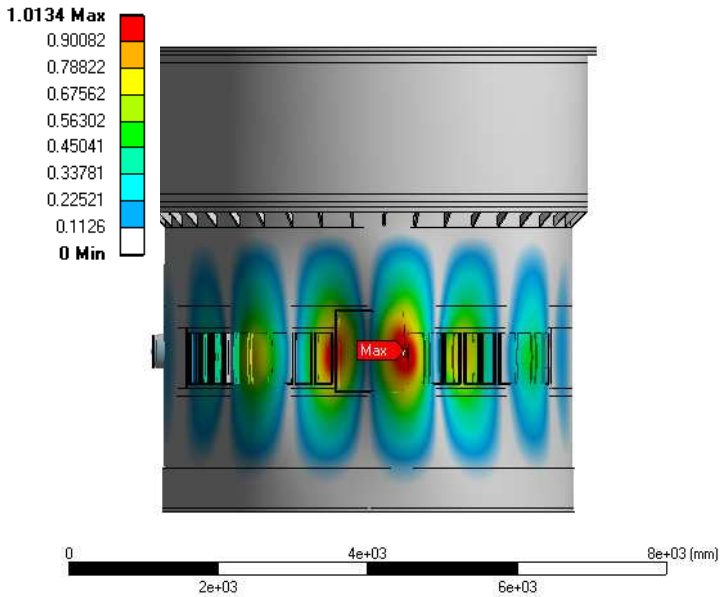


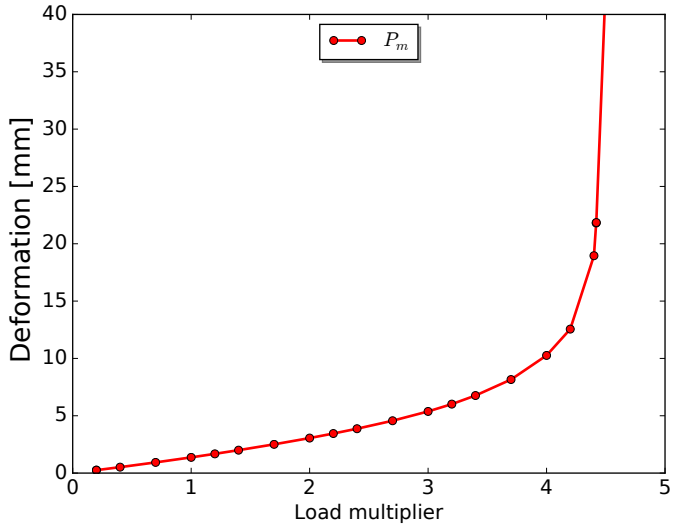
Redesign work

AVS+CADINOX changes requested

The thickness of the flanges and lateral walls were increased to withstand the loads produced in the machining process. The connection between both sections relies on bolted flange seal welded on site.

Buckling analysis. Safety factor > 4





Monolith Vessel: Remarks

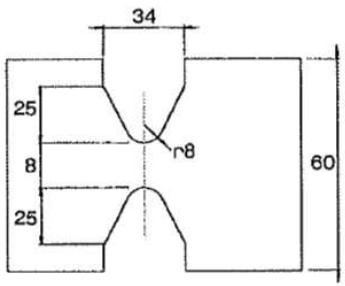
Combination of submerged arc and TIG

The combination of RCC-MRx manufacturing rules for 316L and the vacuum requirements limit the welding options. The solution selected was to combine submerged arc (121) and semiautomatic TIG (141) in most of the welding lines.

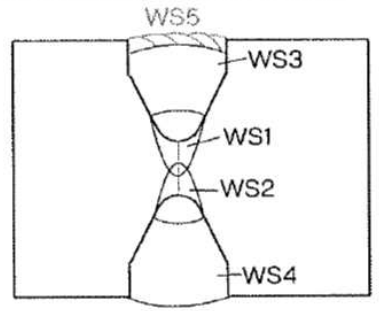
Example of welding strategy for monolith vessel

Joint Details (Sketch)/Detalles de la Unión (Croquis)*

Joint Desing/Diseño de la junta



Welding Sequence/Secuencia de soldeo



Welding parameters/Parámetros de soldeo

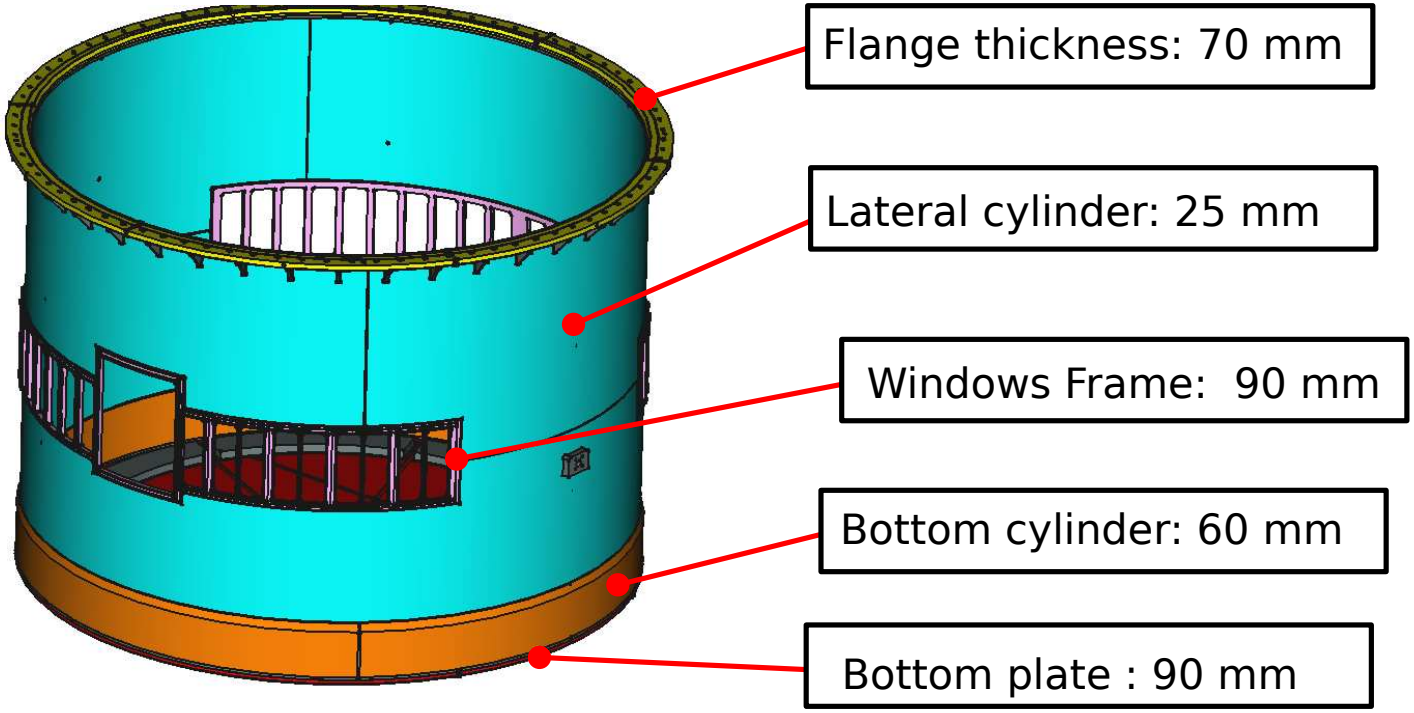
Weld bead Cordón	Process Proceso	Filler metal size Dimensiones del metal de aporte	A Range Intensidad (A)	V Range Voltaje (V)	Current type polarity Tipo de corriente Polaridad	Travel speed Velocidad avance (cm/min)	Thermal supply* Aporte térmico* (kJ / mm)
WS1 - WS4 WS5	121 141	Ø 2,4 - Ø 3,2 Ø 1,2	375-525 200-250	28-30 12-14	DC REVERSE DC DIRECT	30-40 15-24	1,57-3,14 0,36-0,84

Monolith Vessel: Remarks

Thicknesses from 25 to 90 mm

The thickness of the vessel during the welding is related with the needs in the final machined areas. The frame for the windows only covers the windows area.

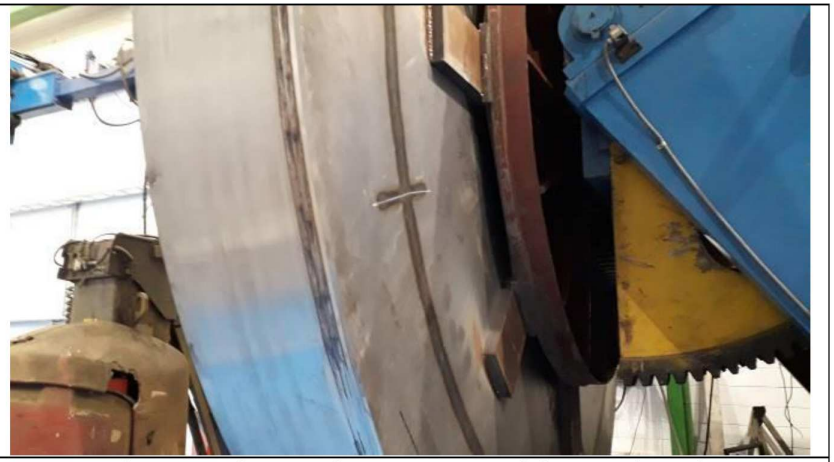
Vessel thickness during welding



Monolith Vessel

Manufacturing 18-11-2019 to 20-10-2020

Lower part body assembled by tack welding



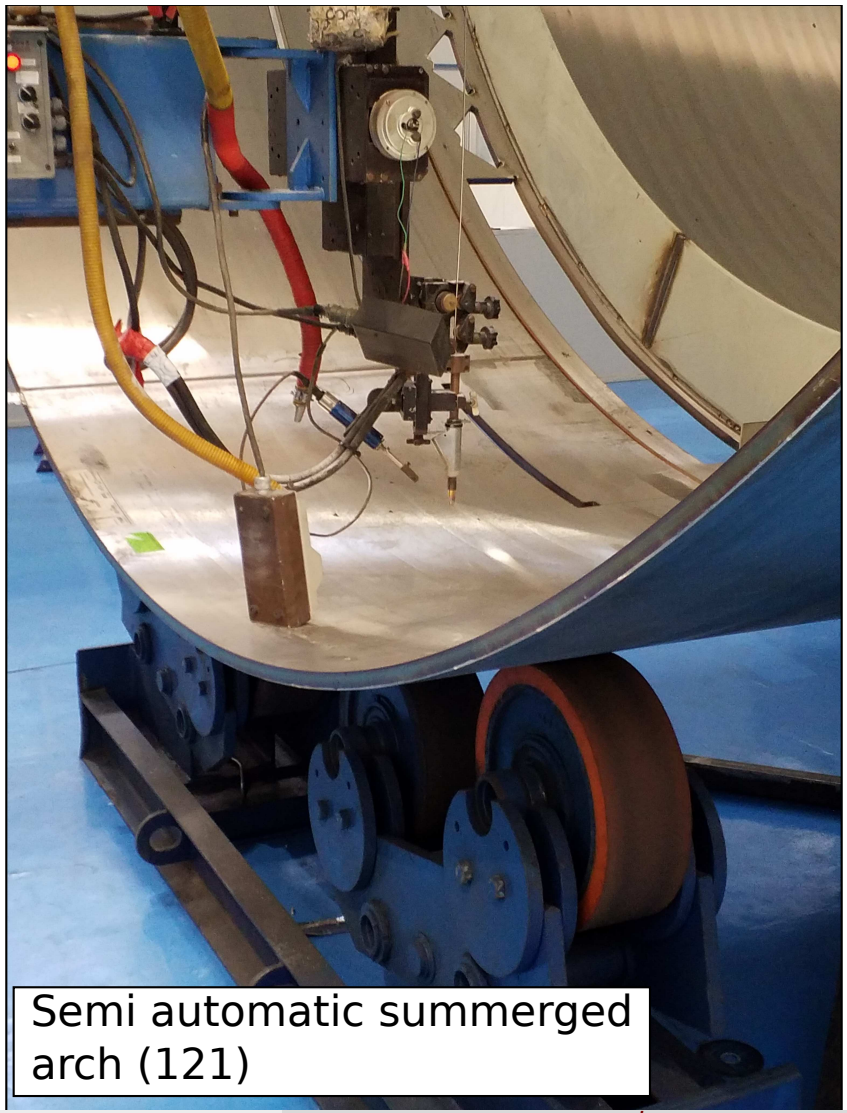
Lower plate to lower ring weld completed

Rear window structure before bending

Rear window welding view

Monolith Vessel

Manufacturing 18-11-2019 to 20-10-2020



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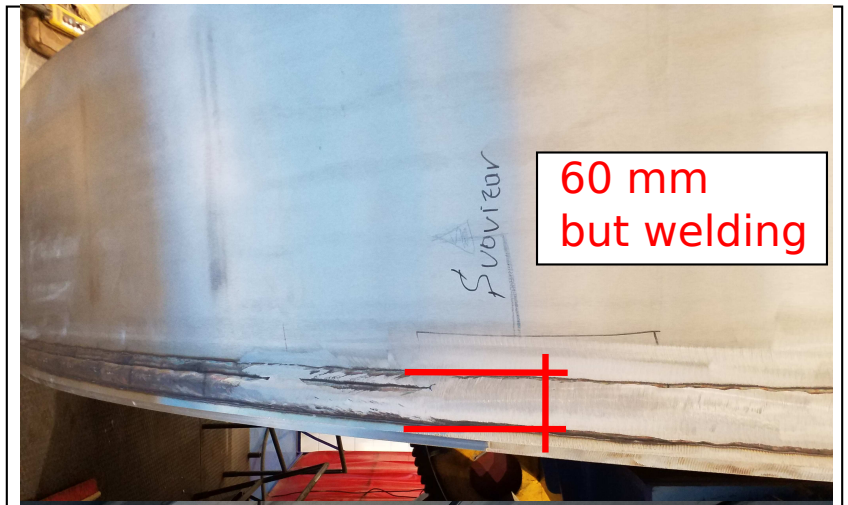


Monolith Vessel

Manufacturing 18-11-2019 to 20-10-2020

Upper part taken out of positioner

Visual inspection of welds

Lower body ready to be placed in positioner

Window weld joints preparation detail

Monolith Vessel

Manufacturing 18-11-2019 to 20-10-2020

Lower part already out of positioner

Inside surface view

Lower part in machining center

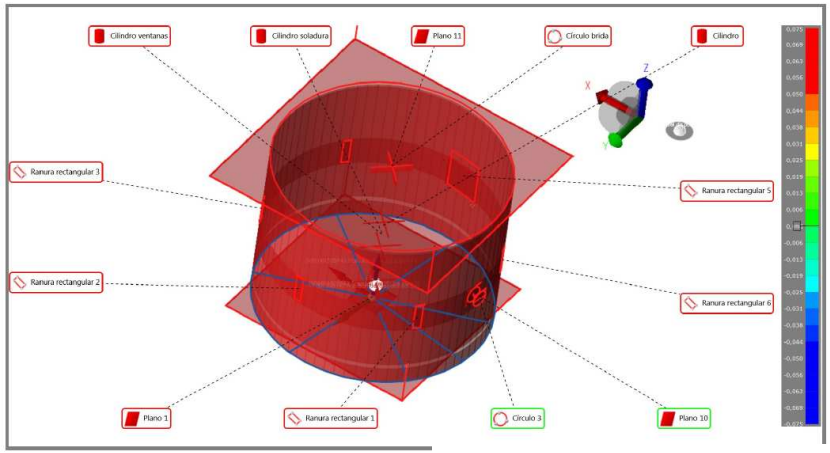
Roughing of windows

Monolith Vessel

Metrology intermediate control steps

The intermediate metrology shows deformations above the expected values in the windows frame. However, there is still large amount of extra material for final machining.

Dimensional control previous to pressure test (Mar 6^{th}, 2020)



Cilindro soladura *Lecturas:108.*

	real	nominal	Desv	- tol.	+tol.	FueraTol
Diámetro	5.390,943mm			-0,050mm	0,050mm	
Cilindricidad	15,079mm		15,079mm	0,000mm	0,050mm	15,029mm

Cilindro *Lecturas:80.*

	real	nominal	Desv	- tol.	+tol.	FueraTol
Diámetro	5.396,545mm			-0,050mm	0,050mm	
Cilindricidad	16,547mm		16,547mm	0,000mm	0,050mm	16,497mm

Monolith Vessel

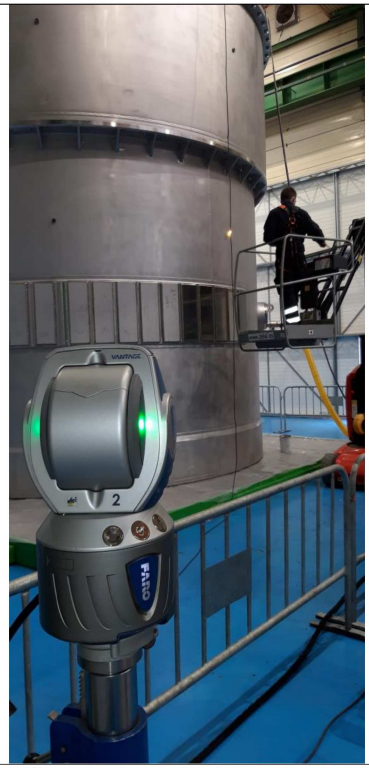
Pressure completed

Pressure test completed without incidences. Pre and post test metrology shows only elastic deformation during the test as it was expected.

Pressure test completed on April 29^{th}, 2020

General view of vessel

Dimensional control before test



Dimensional control during pressure test

Monolith Vessel

Pressure and vacuum test completed

Vacuum level completed. Values measured almost a factor of 10 better than the acceptance criteria for leaks and vacuum level.

Vacuum test completed May 15^{th}, 2020

DEW POINT RESULTS	Value	Units
Dew Point must be lower than	-40,0	°C
Dew Point Temperature	-53,9	°C
PRESSURE RESULTS	**Value**	**Units**
Pressure must be lower than	1,0E-05	mbar
Pressure	1,0E-06	mbar
LEAK TEST RESULTS	**Value**	**Units**
Leak tightness requirement must be lower than	2,00E-08	mbar l s^{-1}
Leak evaluation	6,57E-09	mbar l s^{-1}
PRESSURE RISE TEST RESULTS	**Value**	**Units**
Slope Differential must be lower than	10%	mbar l s^{-1}
Initial Pressure Rise Slope	1,34E-03	mbar l s^{-1}
Final Pressure Rise Slope	1,30E-03	mbar l s^{-1}
Differential Pressure Rise	0,004%	mbar l s^{-1}

Monolith Vessel

Machining of the windows restarted in June 2020

After several clarification work in the functional tolerances of the windows the machine work restarted on June 2020. On August $4^t h$, 2020 the manufactured reported "instability in the vessel". The machining velocity was reduced to 1/3 of the previous speed.

Inspection visits on July 2020.

Monolith Vessel

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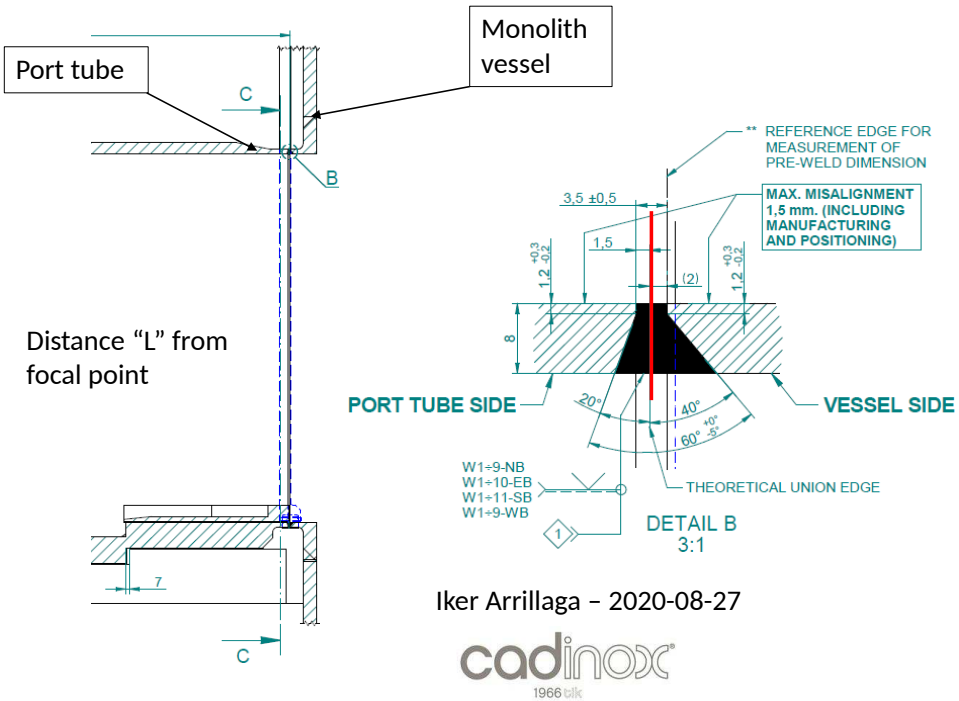
Monolith Vessel

Strategy to achieve window tolerances

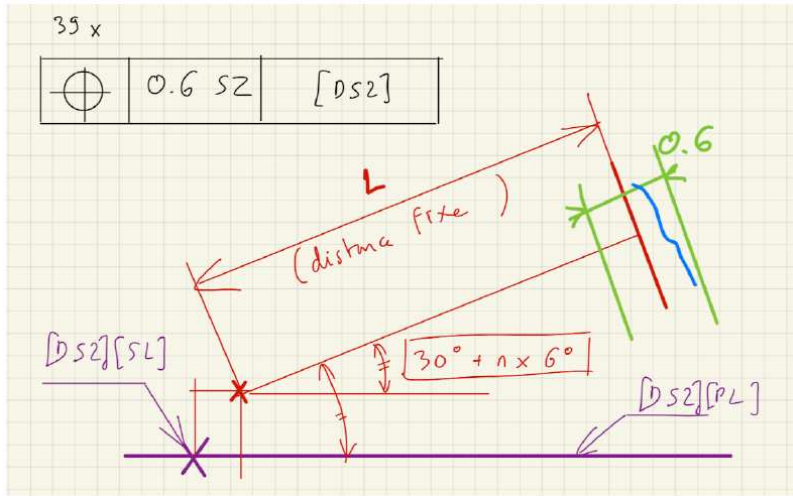
The manufacturer selected a two step machining approach (after the premachining):

- 1^{st} stage from 3 mm to 1.5 mm.
- 2^{nd} from 1.5 mm to 0.5 mm (finished before August closure)

Window to focal point



Iker Arrillaga – 2020-08-27

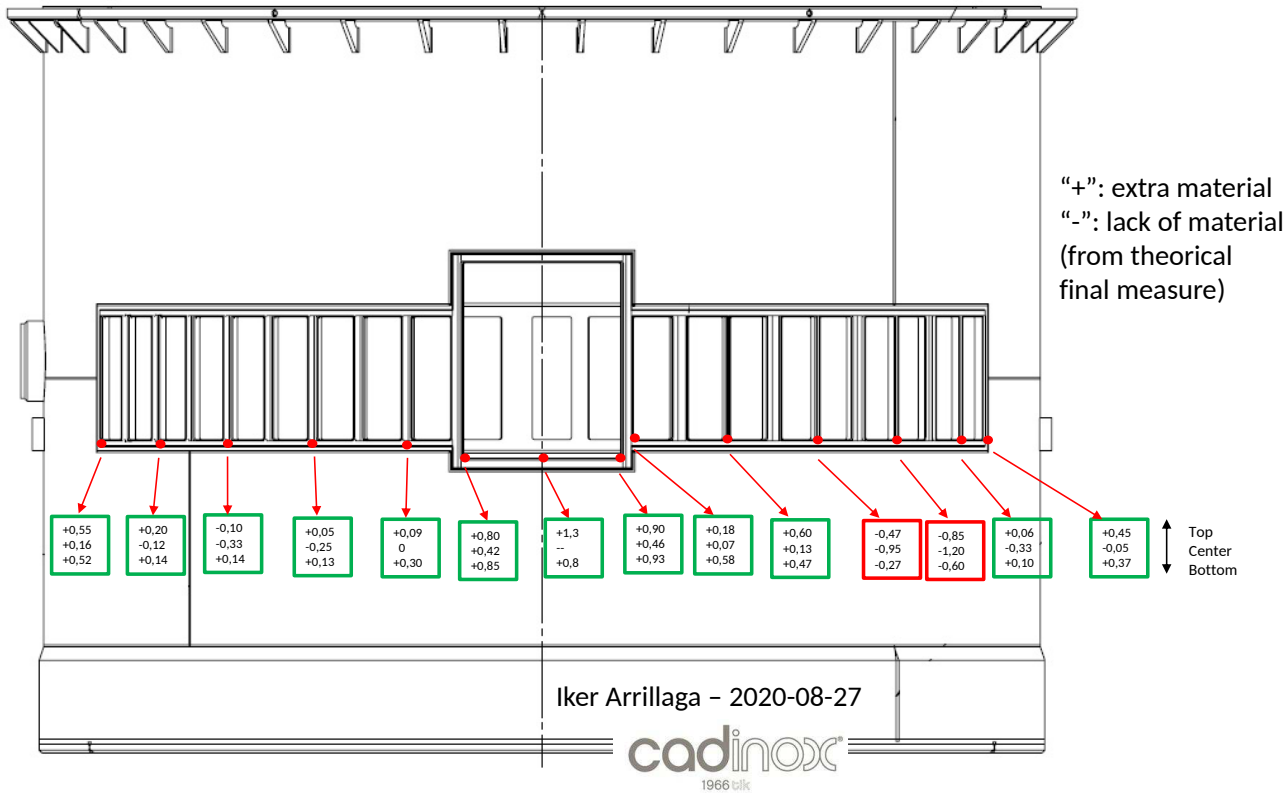


Monolith Vessel

Strategy to achieve window tolerances

After the 15 days August closure, the manufactured reported changes in the geometry compared with dimensional control performed after the 2^{nd} machining step.

August $28^{t}h$ dimensional control



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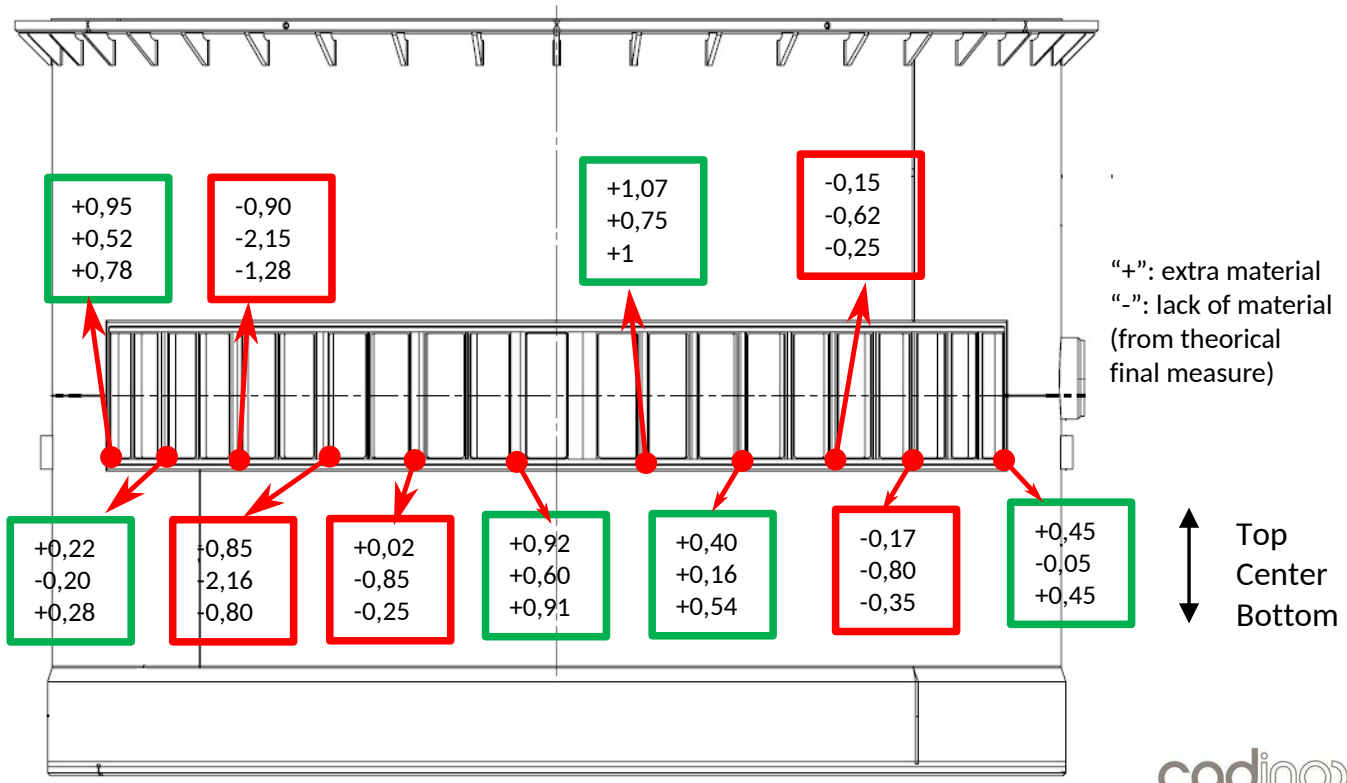


Iker Arrillaga – 2020-08-27

Monolith Vessel

Manufacturer report (I. Arrillaga August, 2021

- Completely unexpected distortion once material is removed from Windows. Pattern of "snake": out in the middle, inside in "1/4" and "3/4" and quite correct in extremities.
- Distance "L" cannot be respected is some Windows (highlighted in red)
- Distance "L" will be final machined to respect dimension in the rest of the Windows as planned (highlighted in green)
- Bottom surfaces and upper flange verified and no distortion.
- First and main hypothesis of root cause (TBC):
  - References and CAD-CAM machining program are correct
  - During 15 days, rested in the vertical lathe, unclumped. Possible "natural" stress relieve and distortion. Temperature range changing from $15^{o}C$-$35^{o}C$.

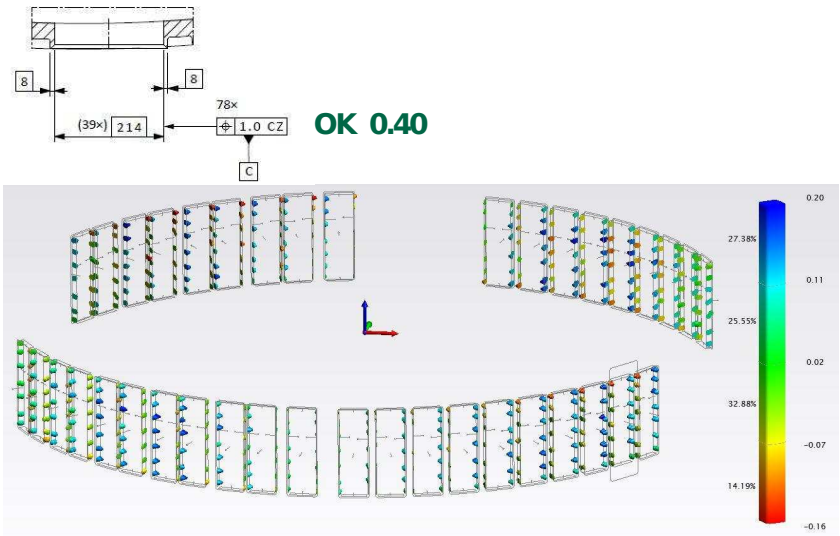
Monolith Vessel

Final machining completion

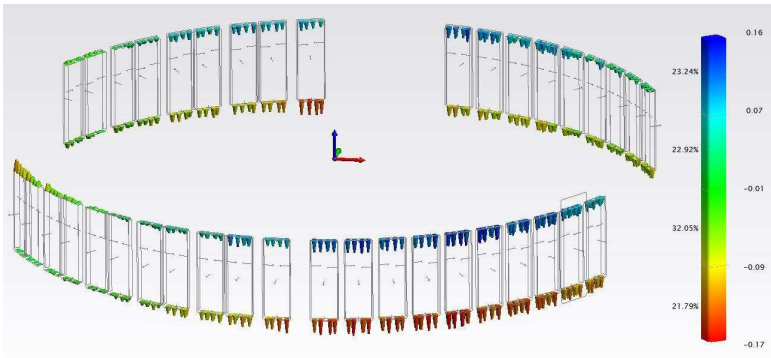
The incidence was evaluated with ESS and the deviations in "L" distance can be compensated adjusting the length of the port tubes. The final tolerances of the vessel shows fluctuations in the position of the welding plane and good shape tolerances of the bevel lated to the center of the welding plane.

FAT metrology report

NN BAR FRAME



PORTS FRAME



OK 0.34

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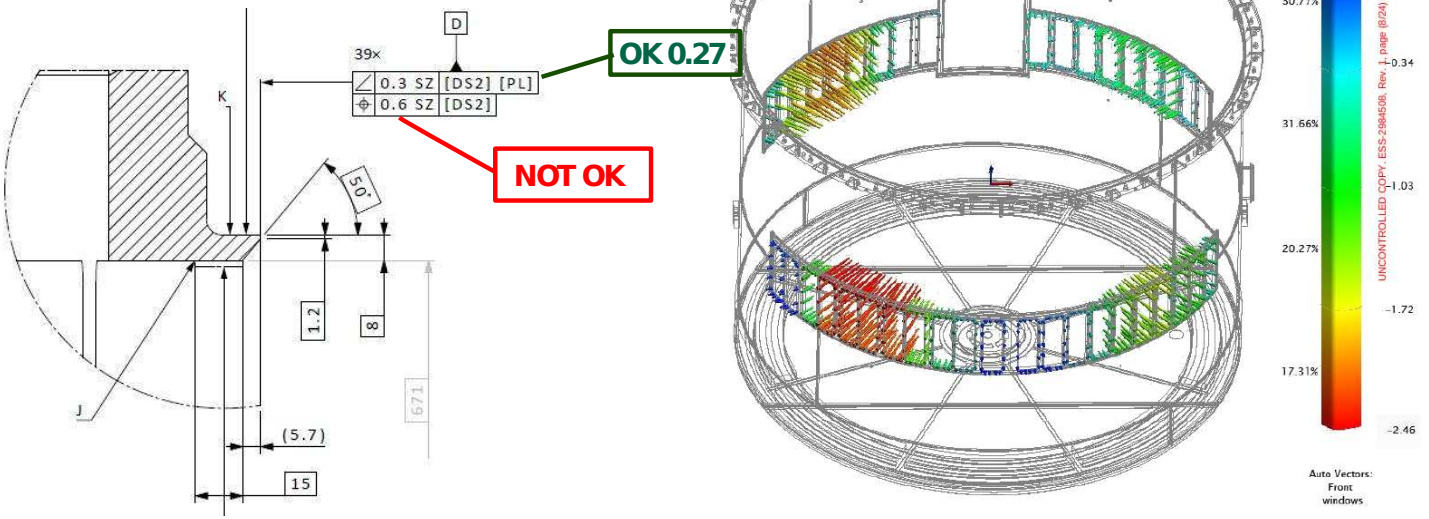

Conclusions

Main remark

- The manufacturing process of the vessel produces large residual stresses
- The vessel shows unexpected deformations during all the production processes (April 2021 metrology).
- The machining of the windows frames produces stress relaxations ($\sim$2-4 mm). This process was done in control conditions at low temperature and slow material removing. (June-August machining)
- After the windows machining, additional relaxation were produced (August 2021)
- Cadinox consider that additional distorsions of the vessel will be produced during the welding to the ports ($>$ 3-5 mm)