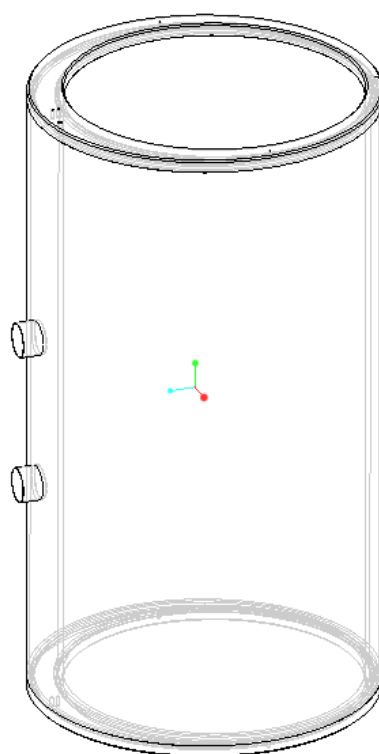


FEA calculation

Aluminum Inner Shell NIKHEF



11-0082C
DeMaCo P100331



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Revision	Date	By	Checked	Issue
A	23-03-2011	RvR	HdG	Fixation pins and load case pressure test added
0	21-03-2011	RvR	HdG	First release

Summary

DeMaCo has to design and fabricate an aluminum inner shell for cryogenic cooling for NIKHEF. In this report stresses are calculated using FEA software. These stresses are checked for compliance with AD 2000 D1 (internal pressure) and D6 (external pressure).

Operating conditions:

- $P_{\text{operating}} = 1.5 \text{ barg}$
- $T_{\text{operating}} = -196 \text{ to } +100^{\circ}\text{C}$

Design limits operating:

- $P_{\text{design}} = 1.5 \text{ barg}$
- $T_{\text{design}} = +150^{\circ}\text{C}$

Leakage testing:

- $P_{\text{leakage test}} = -1.0 \text{ barg (Full Vacuum)}$
- $T_{\text{leakage test}} = 20^{\circ}\text{C}$

Test pressure:

- $P_{\text{test}} = 3.33 \text{ barg}$
- $T_{\text{test}} = 20^{\circ}\text{C}$

Weight of components:

- Weight of vessel (517 kg)
- Nitrogen liquid (216 kg distributed over internal surfaces).
- Bearing load in fixation 4 pins Ø10: 7330 / 4 pins = 1830 N each.

No nozzle loads are defined.

Material type: Aluminum Al 5754

The computed stresses are compared with the maximum allowable stresses according to AD 2000.

Conclusion

- The shell complies with the requirements of AD 2000

1 Introduction

DeMaCo has to design and fabricate an aluminum inner shell for cryogenic cooling for NIKHEF. In this report stresses are calculated using FEA software. These stresses are checked for compliance with AD 2000 D1 (internal pressure) and D6 (external pressure).

All dimensions are in mm

2 Inner shell properties

2.1 Components

The inner shell consists of two pipes with an 32 mm axis offset.

Inner wall: I.D. Ø950 x 1980 x 15 mm

Outer wall: O.D. Ø1120 x 1980 x 12 mm

Baffle: thickness 40 mm

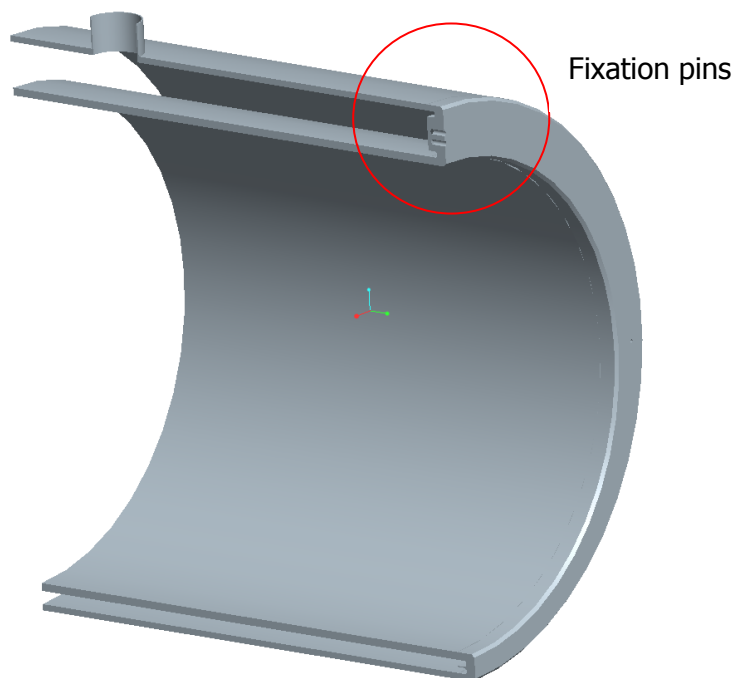
Nozzle: DN100 x 3

Total weight of shell: 517 kg

Total weight of Nitrogen liquid (density 800 kg/m³): 216 kg

The vessel is fixed by two times two pins connected to the Baffles.

See appendix 1 for a drawing of the model, directly generated from the model.



Figuur 1: FEA model (with two symmetry planes)

2.2 FEA analysis

The FEA analyses are performed using the software package Pro/MECHANICA. The analyses are linear elastic, no plastic material behavior is incorporated. Only solid elements are used, with a maximum element order of 9 after the second calculation step. The 9th order polynomial describes the geometry and stresses with a high level of accuracy, instead of increasing the density of mesh elements like traditional FEA packages do. All analyses for this project are performed using solid elements.

2.3 Loads

Operating conditions:

- $P_{\text{operating}} = 1.5 \text{ barg}$
- $T_{\text{operating}} = -196 \text{ to } +100^{\circ}\text{C}$

Design limits operating:

- $P_{\text{design}} = 1.5 \text{ barg}$
- $T_{\text{design}} = +150^{\circ}\text{C}$

Leakage testing:

- $P_{\text{leakage test}} = -1.0 \text{ barg (Full Vacuum)}$
- $T_{\text{leakage test}} = 20^{\circ}\text{C}$

Test pressure:

- $P_{\text{test}} = 3.33 \text{ barg (PED: } 1.25 * 80/45 * 1.5)$
- $T_{\text{test}} = 20^{\circ}\text{C}$

No nozzle loads are defined.

Weight of components:

- Weight of vessel (517 kg)
- Nitrogen liquid (216 kg distributed over internal surfaces).
- Bearing load in fixation 4 pins Ø10: 7330 / 4 pins = 1830 N each.

2.4 Material properties

Material type: Aluminum Al 5754

Materials according to AD 2000-Merkblatt W6/1, D1.2003

Temperatures valid between -270°C to $+150^{\circ}\text{C}$

Table 2: Al 5754 material properties according to AD 2000

Type and thickness	Condition	0.2% limit -270 to 100 °C [N/mm ²]	1.0% limit 150 °C [N/mm ²]	Tensile strength [N/mm ²]
Tube (0.3 to 10)	O/H111	80	45	180
Plate (25 to 50)	H112	80	45	190

2.5 Corrosion allowances

Corrosion allowance is 0 mm.

2.6 Load cases and evaluation of results

With Pro/MECHANICA, stresses and displacement are computed. The stresses which are shown in the various figures the average stress by the definition of Von Mises.

Load case 1 (Design)

Primary load:

- $P_{\text{design}} = 1.5 \text{ barg}$
- $T_{\text{design}} = +150^{\circ}\text{C}$
- Weight of components (Weight of vessel and nitrogen. Fixation on 4 pins).

Secondary load

- No secondary loads

Load case 2 (Full Vacuum)

Primary load:

- $P_{\text{design}} = -1 \text{ barg (Full Vacuum)}$
- $T_{\text{design}} = 20^{\circ}\text{C}$

Secondary load

- No secondary loads

Load case 3 (Hydro test)

- $P_{\text{test}} = 3.33 \text{ barg}$
- $T_{\text{test}} = 20^{\circ}\text{C}$

Check

According to AD 2000, the following set of checks must be evaluated:

1. $\sigma_{v;pm} \leq 1.0\% \text{ yield stress} / S$ with S (Sicherheitsbeiwert) according to AD2000 B0, table 2: $S = 1.5$ for normal conditions, $S = 1.1$ for pressure test

2.7 Additional external pressure check according AD2000 B6

The pressure vessel program BabsyWin is used to check buckling due to external pressure according to AD2000 B6 for both shells. Results can be found in appendix 2.

3 FEA model

Table 1: Components in FEA model

Component	Material type	Corrosion allowance	Effective wall thickness
Inner wall	Tube 15 mm	0 mm	15 mm
Outer wall	Tube 12 mm	0 mm	12 mm
Nozzle	Tube 3 mm	0 mm	3 mm
Baffle	Plate 40 mm	0 mm	40 mm

The FEA model has two symmetry planes, one along the shell axis and one normal to the shell axis.

All elements are solid elements.

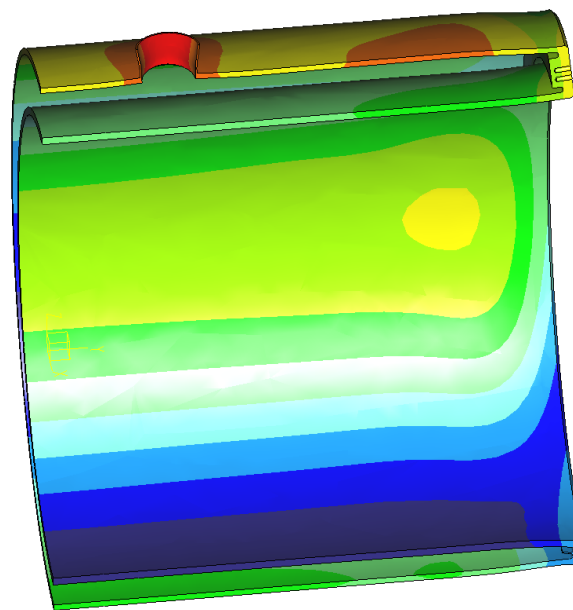
3.1 Loadcase 1: design

Table 2: Summary and evaluation of stresses

Load	Maximum calculated stress	Check (T=150°C)	Result
$\sigma_{v;p}$	28 N/mm ²	30 N/mm ² (1.0% yield/S)	acceptable

Conclusion: the shell complies with the requirements of AD 2000

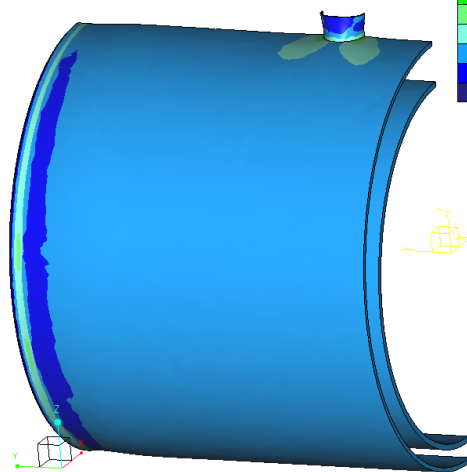
Displacement Mag (WCS)
(mm)
Deformed
Max Disp +1.6915E-01
Scale 2.1925E+02
Combination



"Window1" - Belastingen_rev0 - Belastingen_rev0

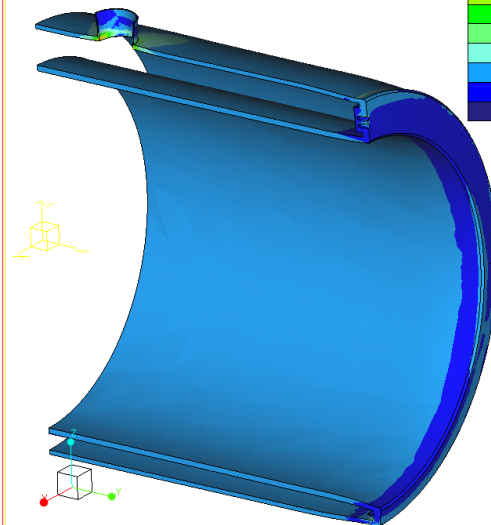
Figure 2: Displacement due to Primary loading (internal pressure). Maximum displacement 0.5 mm.

Stress von Mises (WCS)
(MPa)
Deformed
Scale 2.1925E+02
Combination



"Window1" - Belastingen_rev0 - Belastingen_rev0

Stress von Mises (WCS)
(MPa)
Deformed
Scale 2.1925E+02
Combination



"Window1" - Belastingen_rev0 - Belastingen_rev0

Figure 3: Primary loading (internal pressure only), von Mises stress. $\sigma_{v;pm,max} = 28 \text{ N/mm}^2$

Stress von Mises (WCS)
(MPa)
Location: Components and Layers
Loadset:Druk ; ALUMINIUM_VAT_ALLCAT

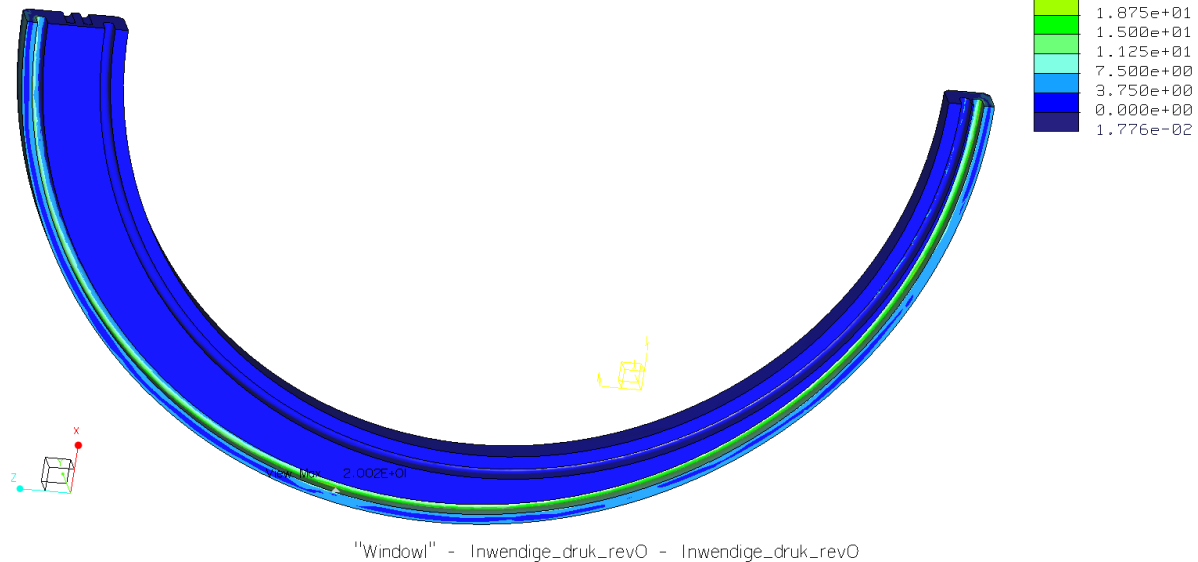
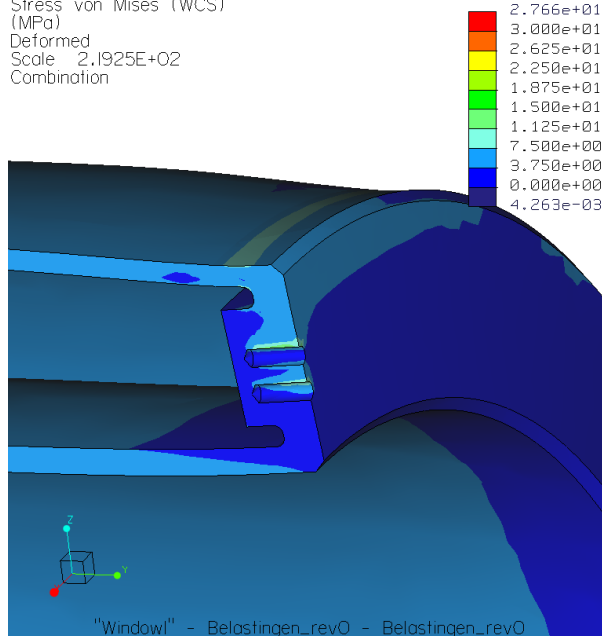


Figure 4: Primary loading (internal pressure only), detail of ring, $\sigma_{v;pm,max} = 20 \text{ N/mm}^2$

Stress von Mises (WCS)
(MPa)
Deformed
Scale 2.1925E+02
Combination



Stress von Mises (WCS)
(MPa)
Deformed
Scale 2.1925E+02
Combination

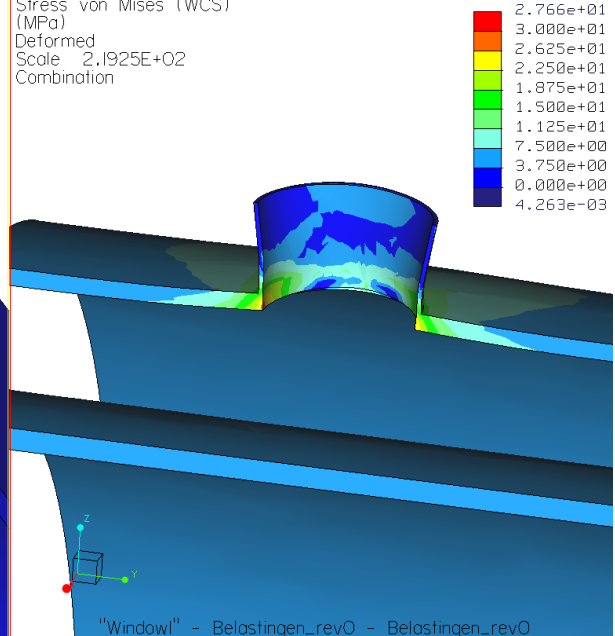


Figure 5: Primary loading (internal pressure only), detail of nozzle and pin holes

$\sigma_{v;pm,max} = 28 \text{ N/mm}^2$

3.2 Loadcase 2: Full Vacuum

Table 3: Summary and evaluation of stresses

Load	Maximum calculated stress	Check (T=20°C)	Result
$\sigma_{v;p}$	19 N/mm ²	53 N/mm ² (0.2% yield/S)	acceptable

Conclusion: the shell complies with the requirements of AD 2000

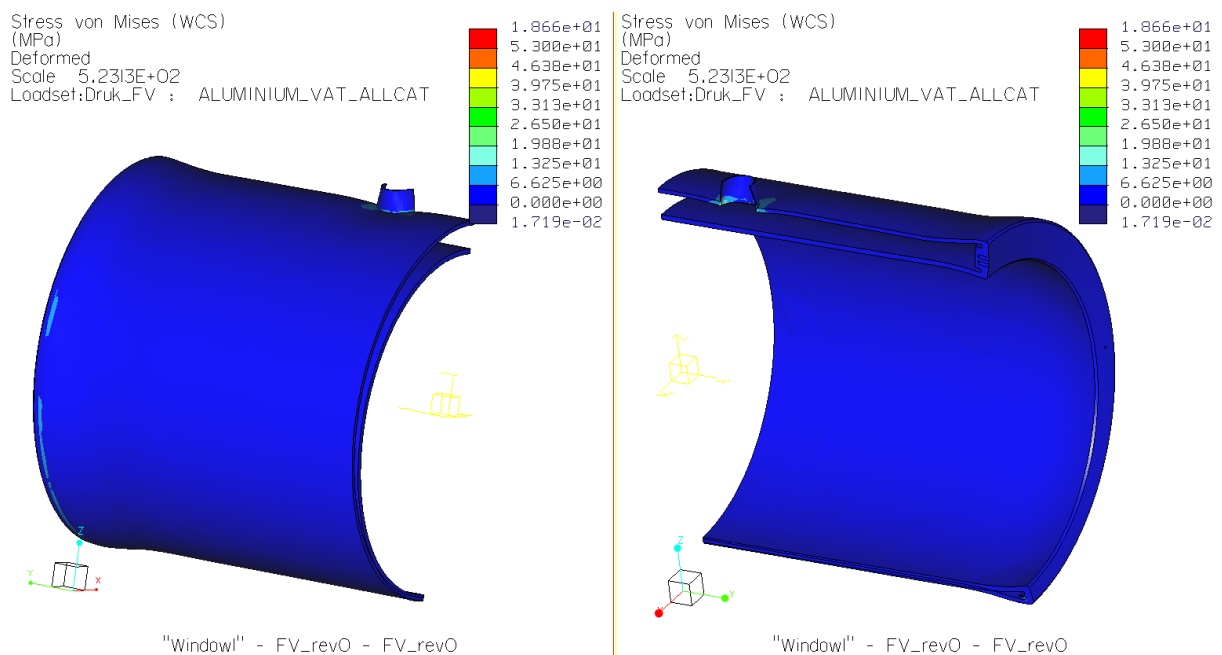


Figure 6: Primary loading (internal pressure only), von Mises stress. $\sigma_{v;pm,max} = 19 \text{ N/mm}^2$

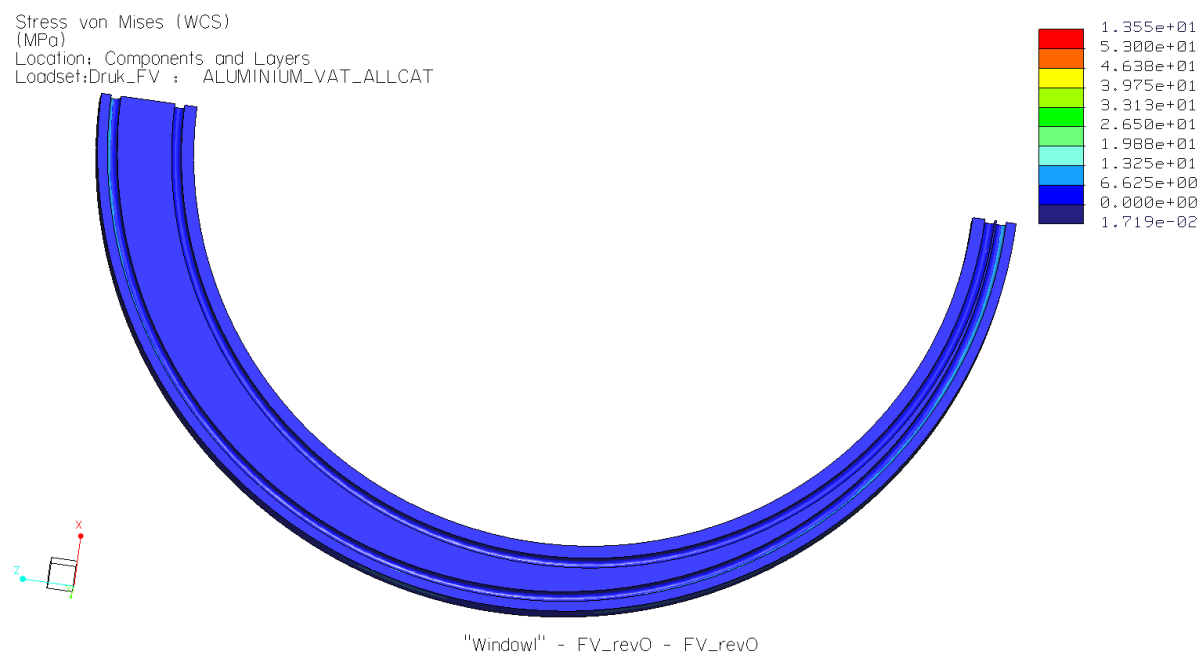


Figure 7: Primary loading (internal pressure only), detail of ring, $\sigma_{v;pm,max} = 13 \text{ N/mm}^2$

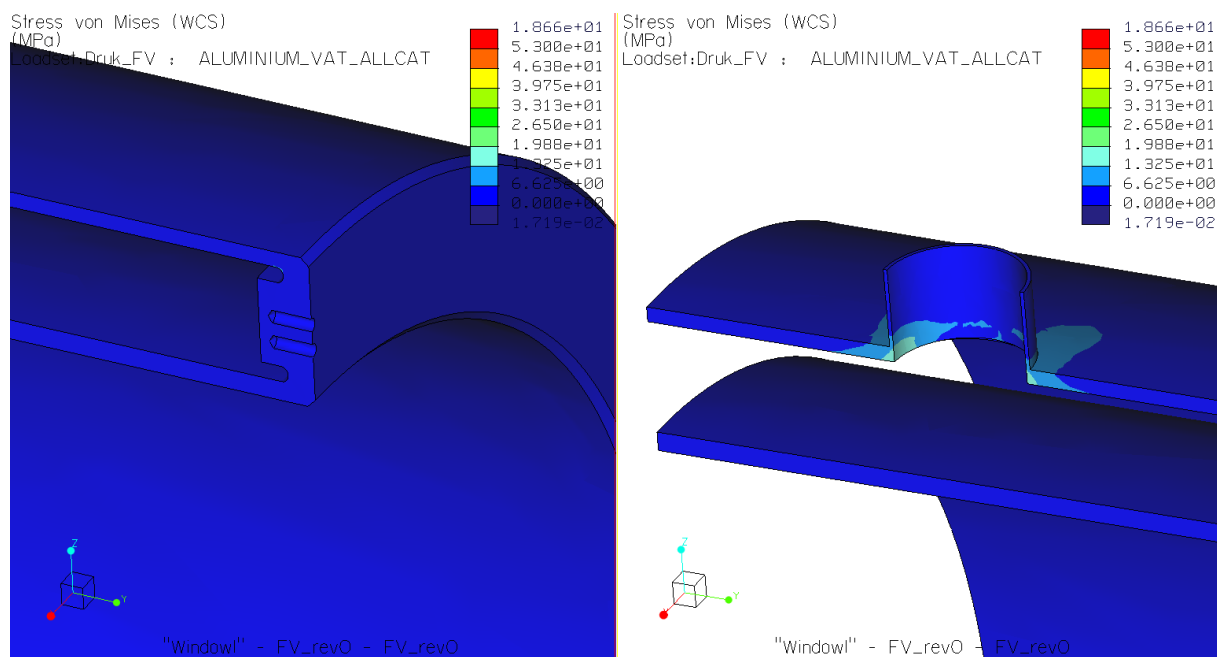


Figure 8: Primary loading (internal pressure only), detail of nozzle and pin holes

$$\sigma_{v,pm,max} = 19 \text{ N/mm}^2$$

3.3 Loadcase 3: Test

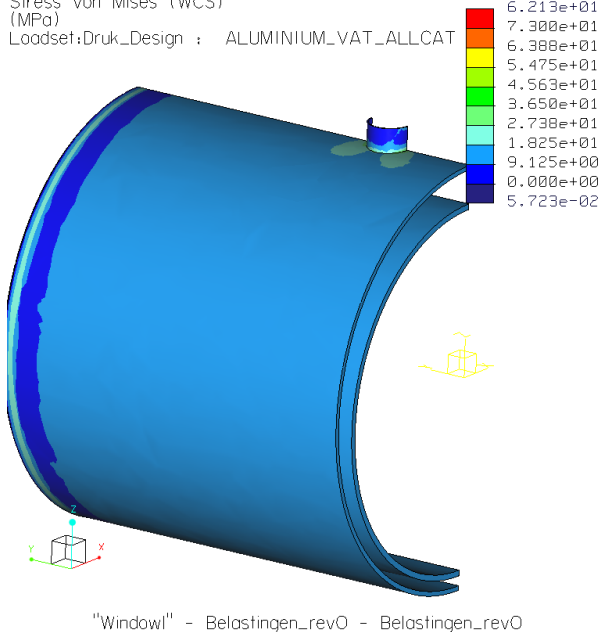
Table 4: Summary and evaluation of stresses

Load	Maximum calculated stress	Check (T=20°C)	Result
$\sigma_{v;p}$	62 N/mm ²	72.7 N/mm ² (0.2% yield/ S_{test})	acceptable

Conclusion: the shell complies with the requirements of AD 2000

Stress von Mises (WCS)
(MPa)

Loadset:Druk_Design : ALUMINIUM_VAT_ALLCAT



Stress von Mises (WCS)
(MPa)

Loadset:Druk_Design : ALUMINIUM_VAT_ALLCAT

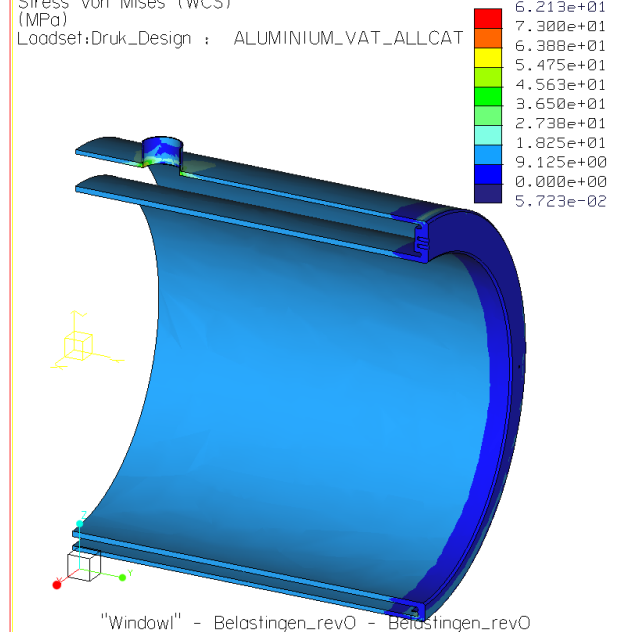
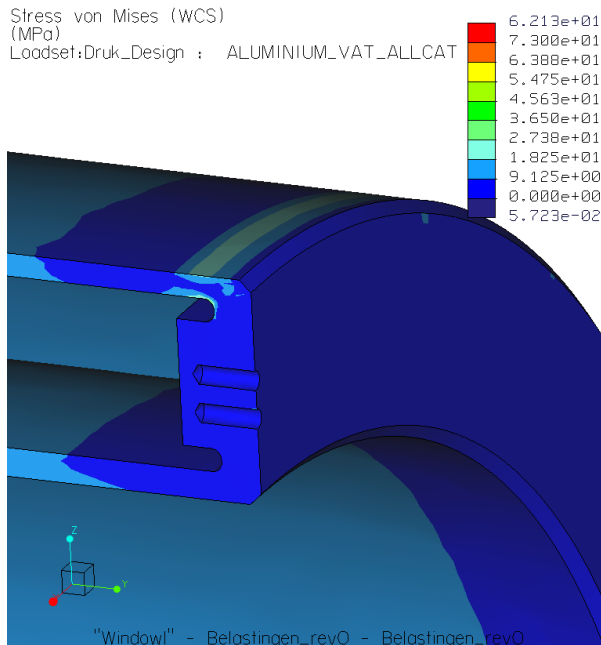


Figure 9: Primary loading (internal pressure only), von Mises stress. $\sigma_{v;pm,max} = 62 \text{ N/mm}^2$

Stress von Mises (WCS)
(MPa)

Loadset:Druk_Design : ALUMINIUM_VAT_ALLCAT



Stress von Mises (WCS)
(MPa)

Loadset:Druk_Design : ALUMINIUM_VAT_ALLCAT

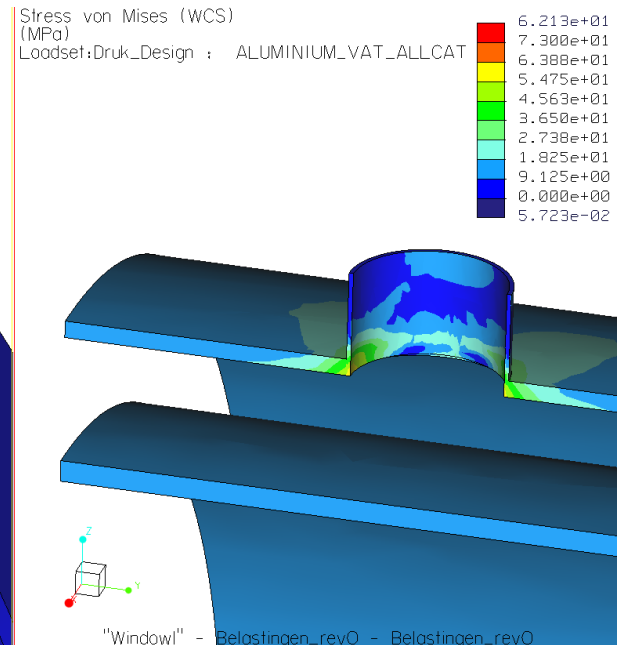


Figure 10: Primary loading (internal pressure only), detail of nozzle and baffle, $\sigma_{v;pm,max} = 62 \text{ N/mm}^2$

4 Results of external pressure check according AD2000 B6

The results of the pressure vessel program BabsyWin in appendix 2 show that the outer vessel is able to withstand an external pressure of 5.4 barg, the inner shell 10 barg according to AD2000 B6 with a safety factor $S=1.1$ (test condition).

Appendix 1: Drawing

See document: 11-0082C Aluminum Inner Shell NIKHEF rev 0 Appendix 1.pdf

Appendix 2: AD2000 B6 external pressure check

See document: 11-0082C Aluminum Inner Shell NIKHEF rev 0 Appendix 2.pdf