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Analytical calculations for the accumulator container

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0 Introduction

This study has the objective of analyzing the structural integrity of the accumulator container, through analytical procedures required by the competition. Previously, a study was conducted to determine the best material for the application and thickness for each component of the container. Both this studies use, as a base knowledge, the Kirchhoff-Love plate model, as well as Roark´s formulas for stress and strain on rectangular plates.

The most important aspects to consider was the accelerations the container has to endure, result of the internal components weight. For this effect some approximations had to be done, explained further in the calculations section. The common approximation between all walls is the non-consideration of the accumulator lid. This component is design to add structural rigidity, but is not taken into consideration in the calculations both for a redundancy factor and safety. In later development of the accumulator this is something to consider as there might be weight to be saved.

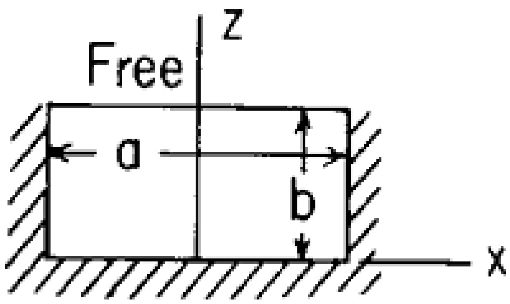
1 Calculations for the Accumulator Container Walls

To ensure a complete analysis of the accumulator container, the calculations were divided into 4 sections: the front walls; the interior walls; the side walls, and the base plate. Each of this walls have to withstand either 40G or 20G of acceleration, maintaining structural integrity. The material used in the entire accumulator is aluminum 6013-T6 and has a yield strength of $351MPa$.

1.1 Front Walls

The front walls are rectangular plates of 570.4mm x 200mm, fixed on 3 edges and free on the fourth (schematic on figure 1). They are 6mm thick. The total tension applied is $149542,43Pa$. Because these walls are also supported by the interior walls an approximation is in place. The front walls are subdivided into it´s 7 sections and analyzed individually.

Figure 1: 3 fixed edges and 1 free edge



The maximum point of stress is at $\pm\frac{a}{2}$, $z = b$ and the formula used to calculate it is:

$$\sigma = \frac{\beta \cdot q \cdot b^2}{t^2} \tag{1}$$

Where:

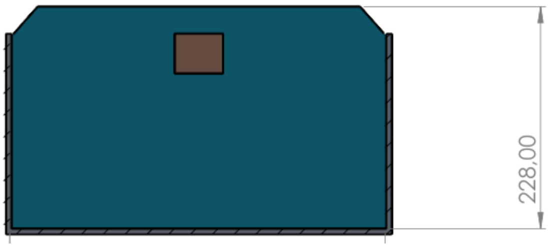
- $\beta = 0,081$ is a geometric parameter obtained empirically (the value used was based on an extrapolation of the values in Roark´s book for a $\frac{a}{b} = 0,4$)(YOUNG; BUDYNAS, 2002).
- $q = 149542,43$ is the load applied
- $b = 0,2$
- $t = 0,006$ is the thickness

The maximum tension achieved is equal to $13,46MPa$

1.2 Interior Walls

The interior walls are considered rectangular plates of 399mm x 228mm, in reality they have cut-out areas for cable management and the corners of the top edge cut as well as showed in figure 2. This is only considered if the tension values calculated get close to the limit has this small areas have little effect on the structure.

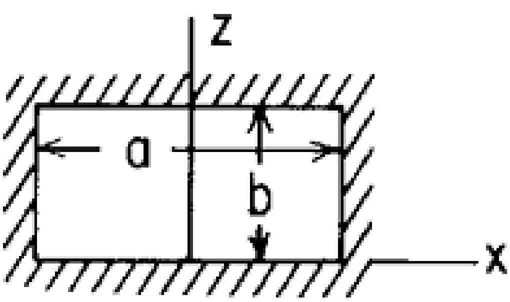
Figure 2: Interior walls



Due to the effect of the lid on the interior plates these are considered fixed on all 4 edges. They are 3mm thick. It´s considered the worst-case scenario which is the last wall, that holds the weight of 6/7 of the accumulator. For redundancy purposes let´s assume all the weight of the accumulator and an acceleration of 40G.
A schematic of the plate is showed below (figure 3). The maximum stress occurs at $x = 0$, $z = b$. It´s used the same formula as in the previous section (1), where:

- $\beta = 0,484$ comes empirically from the relation $\frac{a}{b} = 1.75$
- $q = 31254.7Pa$ is the load applied divided across the 6 walls
- $b = 0,228$
- $t = 0,003$ is the thickness

Figure 3: 4 fixed edges



The result is a maximum stress of $87,38MPa$.

1.3 Side Walls

The side walls have the same geometry as the interior walls so the same approximations are conducted - rectangular plates of 399mm x 228mm. The plates are fixed on 3 edges and free on the fourth (figure 1). They are 6mm thick. These walls hold all the weight of the accumulator in a lateral acceleration of 40G.The equation used is 1, where:

- $\beta = 1,345$
- $q = 187528.03Pa$ is the load applied
- $b = 0,228$
- $t = 0,006$ is the thickness

The maximum stress occurs at $\pm\frac{a}{2}$, $z = b$. The result is a maximum stress of $364.21MPa$. Despite this value being slightly above the yield strength of the material it doesn´t take into account the affect of the lid. This case is not as simple as the interior walls where the lid essentially acts as a forth supported edge. Due to this plate being the outside ones they have extra geometry to bolt on the lid introducing extra strength that can´t be approximated. With that we conclude that because our calculations, without the added strength of the lid, only predicted a a tension 3,7% above the maximum, the side walls are appropriate for the acceleration of 40G. Later in this document FEM simulations are used to validate these assumptions.

1.4 Base Plate

The base plate is a rectangular plate of 570.4mm x 399mm, fixed on all sides. The case in study is a vertical acceleration of 20G, result of the weight of the entire accumulator. An illustration of the plate is shown in figure 3. The maximum stress occurs at $x = 0$, $z = b$. The same equation is used as in the previous sections (1), where:

- $\beta = 0,4356$ comes empirically from the relation $\frac{a}{b} = 2$
- $q = 37479,30Pa$ is the load applied divided across the 6 walls
- $b = 0,399$
- $t = 0,006$ is the thickness

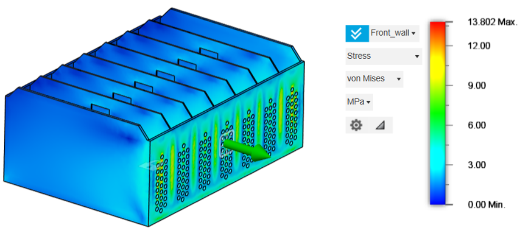
The maximum stress verified is $72,20MPa$, revealing compliance with the regulation.

2 FEM simulations

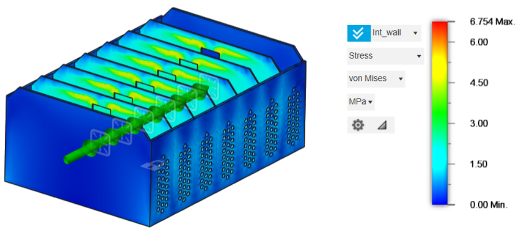
As stated in section 1, FEM simulations were conducted taking into consideration the entire accumulator container. The main objective is to validate the analytical calculations, introducing the effect of the container lid, the cut out areas in the interior walls for cable routing and the openings in the front walls for air flow.

Four situations were simulated, one for each direction of acceleration and one with all the accelerations at the same time. Below are illustrative images of each simulation scenario.

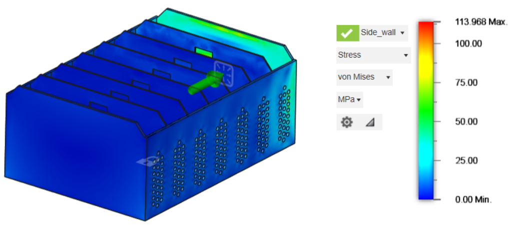
Figure 4: FEM results



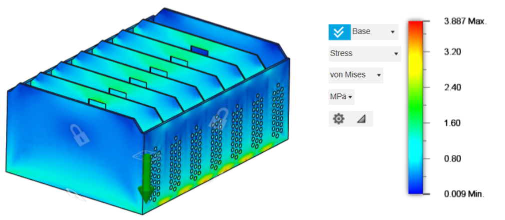
(a) FEM results for the simulation of the front wall under acceleration in the x direction.



(b) FEM results for the simulation of the interior walls under acceleration in the y direction.



(c) FEM results for the simulation of the side wall under acceleration in the y direction.



(d) FEM results for the simulation of base plate under acceleration in the z direction.

3 Conclusion

The FEM simulations have shown that the analytical calculations are valid, as the results are consistent with the expected behavior of the system under various acceleration conditions. The simulations also highlighted the importance of considering the entire accumulator container, including the effects of the lid, cut-out areas for cable routing, and openings for air flow. With that in mind, we can comfortably conclude that our design for the accumulator container is robust and capable of withstanding the expected forces during operation, following all technical requirements.

4 References

References

YOUNG, W. C.; BUDYNAS, R. G. **Roark's Formulas for Stress and Strain**. 7. ed. New York: McGraw-Hill, 2002.