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Analytical calculations for the accumulator mounting brackets

05/06/2025

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0 Introduction

This document serves the purpose of validating the design of the accumulator attachments, making sure they comply with the regulation EV 5.5.8. To that effect this is a compilation of the mechanical profs of the fasteners, the brackets strength and their attachment to the accumulator container for all 3 axis. The brackets are welded to the container, and there for are of the same material, Al 6013-T6.

It´s also included FEM simulation as a way to confirm the analytical calculations.
The images below depict the bracket and the connection to the chassis mount.

Figure 1: Accumulator mounting bracket

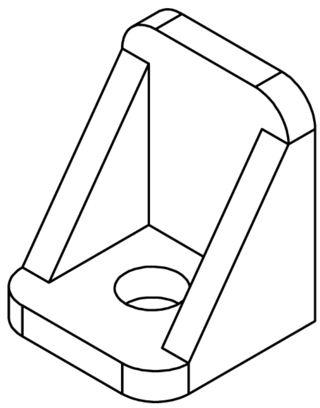
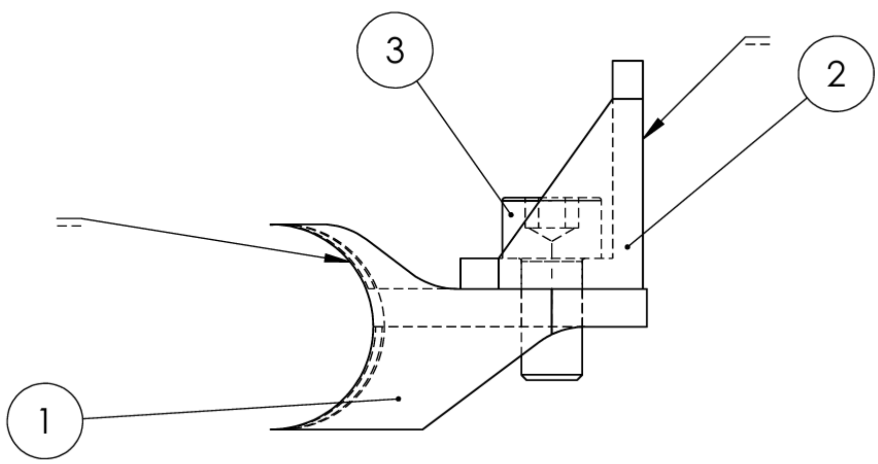


Figure 2: Chassis mount



1 - is the chassis bracket, 2 - is the accumulator bracket, 3 - is the bolt.

1 Calculations of the bracket strength

In the z direction, the bracket suffers a moment, consequence of the weight of the accumulator, and the force applied by the fasteners. The moment is calculated as follows:

$$M = F \cdot d \tag{1}$$

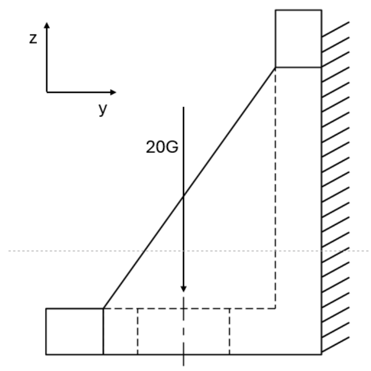
$$F = \frac{m_t \cdot 20 \cdot g}{8} = 1401N \tag{2}$$

where:

- $m_t = 57.11kg =$ is the total mass of the accumulator
- $g = 9.81m/s^{"}$ is gravity
- $d = 0.012m =$ distance between the welded face and the furthest point of the bracket

The reason for the division by 8 is that there are 8 brackets, and the force is distributed evenly between them. The image below is a schematic of the bracket and the forces applied int the z direction.

Figure 3: Schematic of the forces applied in the z direction



The resulting moment is: 16,812 Nm. Applying the formula for the shear stress in a beam:

$$\tau = \frac{M \cdot c}{I_x} \tag{3}$$

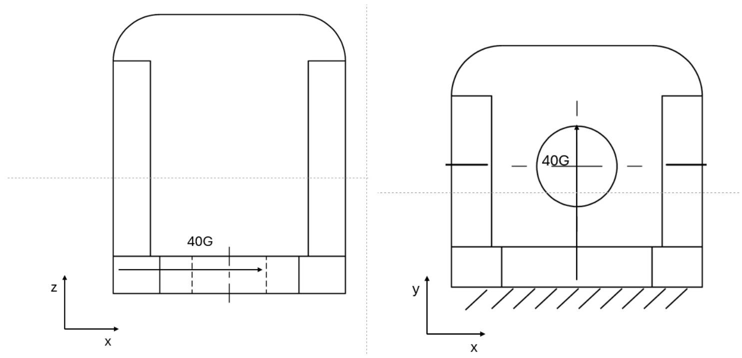
where:

- $M = 16,812Nm =$ is the moment calculated above
- $c = 0.0152m =$ distance from the neutral axis to the outermost edge.
- $I_x = 54142 \cdot 10^{-12} m^4$ is the moment of inertia of the bracket in the x direction, obtained from the CAD model.

The maximum shear stress for this case is: $4,72MPa$, which is well below the yield strength of the material ($351MPa$).

For the second and third cases, the x and y direction, the base of the screw is the area that suffers the most stress. The calculation is the same for both cases, as the forces are the same, and the area is the same. The only difference is the direction of the force applied. The images below illustrate the forces applied in the x and y direction, respectively.

Figure 4: Schematic of the forces applied



(a) Schematic for the x direction

(b) Schematic for the y direction

To calculate the shear stress in this case, we use the formula:

$$\tau = \frac{F}{A_{efetiva}} \tag{4}$$

where:

- $F = \frac{m_t \cdot 40 \cdot g}{8} = 2801N$ is the force
- $A_{efetiva} = \frac{\pi \cdot d \cdot h}{2} = 50,27mm^2 =$ is the effective area of the base of the screw ($h = 4; d = 8$).

With this, the maximum calculated stress is 55,72 MPa, still below the yield strength of the material.

2 Calculations of the weld strength

Another important aspect of the bracket is the welds. The welds are responsible for holding the bracket to the accumulator container and also have to withstand the forces applied to the bracket. To properly analyze the welds, 3 parameters are evaluated: the skin shear strength, the perimeter shear strength and the tear-out strength.It´s important to consider the welded walls of the accumulator are 6mm thick aluminum 6013-T6.

2.1 Skin shear strength

The skin shear strength refers to the ability of the plate being welded (accumulator external wall) to resist the shear forces applied to it in the region adjacent to the weld.
The formula used to calculate this stress is the following:

$$\tau_{skin} = \frac{F}{A_{skin}} \tag{5}$$

where:

- τ_{skin} is the skin shear stress;
- $F = 2801N$ is the force applied to the weld (40G in the y direction divided by the 8 brackets);
- $A_{skin} = 630mm^2$ is the area of the skin adjacent to the weld ($thickness \times weld\ length$).

Applying the formula we get a maximum stress of: $4,45MPa$. This value is below the allowed shear stress of the aluminum, which is $246MPa$ ($\tau_{allowable} = 0.7 \cdot yield\ strength$).

2.2 Perimeter shear strength

This strength is characteristic of the weld itself and is dependent of the direction of the shear force applied to the weld.
With that, it needs to be considered two scenarios: the force is being applied in the direction of the weld (parallel) and the force is being applied perpendicular to the weld.Because the brackets are welded in all four edges, the analyses is performed for the vertical (z axis) and horizontal (x axis) welds.
To ensure the welds are strong enough, the welds need to comply with two criteria, one for perpendicular forces (6) and one for parallel forces (7).

$$a \geq \frac{\sigma \cdot t}{\sqrt{2} \cdot f_w/\gamma} \tag{6}$$

where:

- $a = 2.8$ is the weld throat size ($0.7 \cdot bracket\ thickness$);
- $\sigma = F/A = 1.90MPa$ is the stress applied to each weld (hence /2; $A = 739 * 2$ is the are of contact from de CAD model);
- t is the height of the welded plate in the direction of the load;
- $f_w = 35MPa$ is the weld resistance from Eurocode 9;
- $\gamma = 1.25$ is the partial safety factor.

$$a \geq \sqrt{\frac{2}{3}} \cdot \frac{\tau \cdot t}{f_w/\gamma} \tag{7}$$

where:

- $a = 2.8$ is the weld throat size;
- τ is the shear stress applied to the weld ($0,95MPaforthezweldand1,9MPaforthexweld$);
- t is the height of the welded plate in the direction of the load;
- $f_w = 35MPa$ is the weld resistance from Eurocode 9;
- $\gamma = 1.25$ is the partial safety factor.

For the vertical welds (z axis), the height of the welded plate is $t = 25mm$. The perpendicular forces result in $2,8 \geq 1,2$, which is true, and the parallel forces result in $2.8 \geq 0.64$, which is also true.
The horizontal welds (x axis) have a height of $t = 30mm$. The perpendicular forces result in $2.8 \geq 1.44$, which is true, and the parallel forces result in $2.8 \geq 1,66$, which is also true.

As both criteria are satisfied, the welds are considered strong enough to withstand the forces applied to them.

2.3 Tear-out strength

This checks whether the base material will tear out around the weld zone. Tear-out usually refers to bolt or rivet holes, but in welds, this can be interpreted as failure of material just adjacent to the weld from combined shear + tension. A general formula for tear-out strength is:

$$F_{tear-out} = 2 \cdot t \cdot l_e \cdot \tau_{allowable} \tag{8}$$

where:

- $F_{tear-out}$ is the tear-out strength;
- $t = 6mm$ is the thickness of the welded plate;
- $l_e = 30mm$ is the effective length of the weld (length of the weld in the direction of the load);
- $\tau_{allowable} = 0.7 \cdot \sigma_{yield} = 0.7 \cdot 351MPa = 245MPa$ is the allowable shear stress for the aluminum.

The 2 factor is used because the weld is present on both sides of the plate.
Applying the formula we get a tear-out strength of $F_{tear-out} = 88,2kN$, meaning that´s the force required to tear out the weld from the plate. Has the maximum force in the direction of tear-out (y direction) is $\frac{20 \times g \times m_{accumulator}}{8} = 2801N$ it´s comfortable to say the weld is compliant.

3 Calculations of bolts

First of all, let´s define general assumptions. By regulation the accumulator enclosure must withstand 40g in the horizontal directions and 20g in vertical directions. The accumulator has a total mass of 57.11 Kg and 8 points that the forces will be distributed, resulting in a force for each connection of:

- $F_x = 2801N$ (horizontal direction);
- $F_y = 2801N$ (horizontal direction);
- $F_z = 1401N$ (vertical direction).

Our bolt of choice due to space limitations was M8, by regulation minimum bolt grade value must be 8.8 which has an effective are of 36.6 mm^2. The grade 8.8 means the bolt have a yield strength of 800(MPa) with a tensile strength of 80% the yield strength. For the tensile strength we have:

$$F = \frac{k_2 \cdot f_{ub} \cdot A_s}{\gamma_{M2}} \tag{9}$$

where:

- k_2 is a coefficient that takes values $k_2 = 0,63$ for countersunk bolts or $k_2 = 0,9$ otherwise.
- $f_{ub} = 800 \cdot 0,8 = 640MPa$ is the ultimate tensile strength of the bolt depending on the bolt class (8.8 in this case);
- $A_s = 36.6mm^2$ is the nominal tensile stress area of the bolt.
- $\gamma_{M2} = 1.25$ is the partial safety factor for the resistance of bolts in accordance with EN1993-1-8 §2.2(2) Table 2.1 and the National Annex. The recommended value in EN1993-1-8 is $\gamma_{M2} = 1,25$.

The result is a force of 21.1 kN.
For the shear strength we have:

$$F = \frac{\alpha_v \cdot f_{ub} \cdot A}{\gamma_{M2}}$$

where:

- $\alpha_v = 0.6$ is a coefficient that takes values $\alpha_v = 0.6$ for bolt classes 4.6, 5.6, 8.8 or $\alpha_v = 0.5$ for bolt classes 4.8, 5.8, 6.8 and 10.9. When the shear plane passes through the unthreaded part of the bolt $\alpha_v = 0.6$.
- $f_{ub} = 640MPa$ is the ultimate tensile strength of the bolt depending on the bolt class (8.8 in this case);

- $A = 36.6mm^2$ is the appropriate area for shear resistance. When the shear plane passes through the threaded part of the bolt A is equal to the tensile stress area of the bolt A_s. When the shear plane passes through the unthreaded part of the bolt A is equal to the gross cross-sectional area of the bolt A_g.

- $\gamma_{M2} = 1.25$ is the partial safety factor for the resistance of bolts in accordance with EN1993-1-8 §2.2(2) Table 2.1 and the National Annex. The recommended value in EN1993-1-8 is $\gamma_{M2} = 1, 25$.

The result is a force of 14.1 kN.
The bolts are mounted at a vertical configuration, so, the horizontal forces will act as a shear force:

$$2, 8 \text{ (kN)} < 14, 1 \text{ (kN)} \quad \text{SAFE}$$

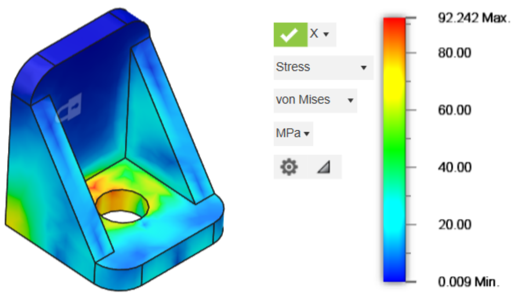
The vertical accelerations will actuate as a normal force:

$$1, 4 \text{ (kN)} < 21, 1 \text{ (kN)} \quad \text{SAFE}$$

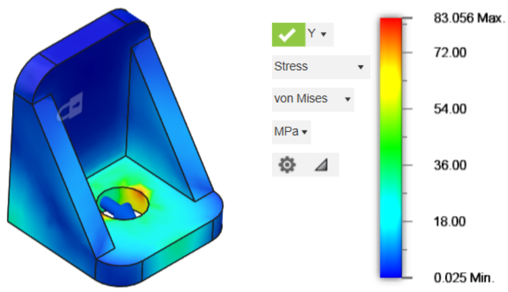
4 FEM simulations

To ensure correlation between the analytical calculations and the FEM simulations, we performed a series of simulations. The simulations were conducted under the same conditions as the analytical calculations, with the same forces applied to the bracket. The results of these simulations are presented in the figures below.

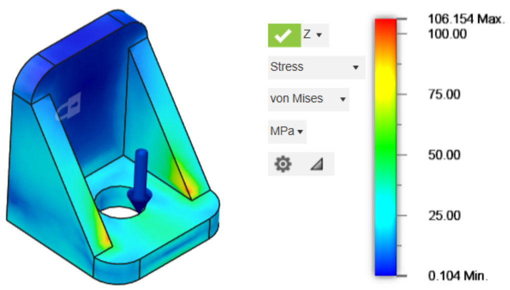
Figure 5: FEM results



(a) FEM results for the x direction.



(b) FEM results the y direction.



(c) FEM results for the z direction.

5 Conclusion

Both the analytical calculations and the FEM simulations reveal that our design for the brackets that hold the accumulator to the chassis are complient with the regulations, withstanding the loads predicted by the latest with a confortable safety margin.

6 References

References