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Analytical Calculations for the cell mounts

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0 Introduction

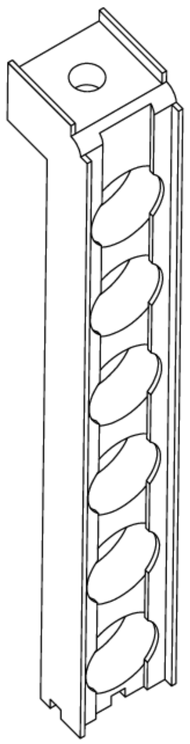
To comply with all technical regulations for the accumulator structure and its components, several analytical calculations must be performed.

To start several assumptions have to be made: the two parts of the cell mount must be analyzed separately, taking into consideration every load applied to it in every direction. As per the regulation, this supports must withstand an acceleration of 40G in the longitudinal and lateral direction, and 20G in the vertical direction. To simplify the explanation and comply with competition guidelines, the standard ISO 8855-2011 will be used.

1 Vertical Cell Mount

The first part to be analyzed is the vertical support where the cells are mounted by friction. Each module has two of these supports and is later mounted on a base plate. The image below shows the vertical mount in question (figure 1).

Figure 1: Vertical Cell Mount



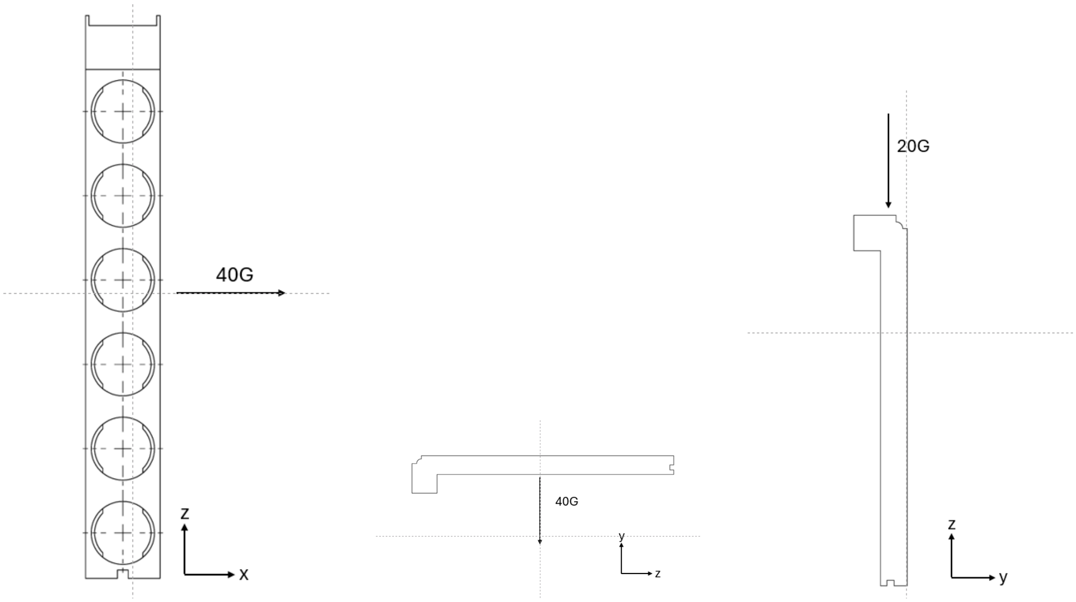
1.1 Assumptions

In the X direction, considering the worst-case scenario, the last support holds the weight of every cell and the support with an acceleration of 40G, suffering compression.

In the Y direction, assuming the worst-case scenario, each support suffers flection. The mount is considered fixed at the bottom and the force caused by the mass and acceleration of the cells is applied at the center. For redundancy purposes, only one mount is analyzed (if it holds in this situation then with the "help" of the second mount, the flection is minimized).

In the Z direction, the support only has a compressive force applied, a consequence of the weight of its own cells.
Each cell has a mass of 0.042 kg and each support a mass of 0.020 kg. Because each segment is independent, only one is considered with 17 modules of 6 cells.
A schematic of the accelerations applied in each direction is shown in figure 5.

Figure 2: Accelerations Schematics



(a) X direction (b) Y direction (c) Z direction

1.2 Calculations

Equations used for X direction:

$$\sigma = \frac{F}{A} \tag{1}$$

Where:

- $F = ma = [(17 \cdot 6 \cdot m_{cell}) + (17 \cdot 2 \cdot m_{mount})] \cdot 9.8 \cdot 40 = 17059.8N$ is the force applied
- $A = 2165.07 \cdot 2 = 4330.14mm^2$ is the area of compression (from the CAD model)

Equations used for Y direction:

$$M_{max} = \frac{F \cdot L}{4} \tag{2}$$

Where:

- M_{max} is the maximum flexural momentum
- $F = 40 \cdot 9.8 \cdot m_{cell} \cdot 6 = 98.78N$ is the force applied
- $L = 164mm$ is the length of the support

$$\sigma = \frac{M_{max} \cdot c}{I} \tag{3}$$

Where:

- σ is the flexural tension

- $c = h/2 = 6mm$
- $I = \frac{bh^3}{12} = \frac{22 \cdot 12^3}{12} = 3.168 \cdot 10^{-9} m^4$ is the inertia

Equations used for Z direction:

$$\sigma = \frac{F}{A} \tag{4}$$

Where:

- $F = ma = 6 \cdot m_{cell} \cdot 9.8 \cdot 20 = 49.38N$ is the force applied
- $A = 343.68 \cdot 2 = 687.36mm^2$ is the area of compression (from the CAD model)

1.3 Results

Trough a quick research of material databases and datasheet, for unfilled PETG the compressive strength is around $60MPa$ and the flexural strength is around $70MPa$.

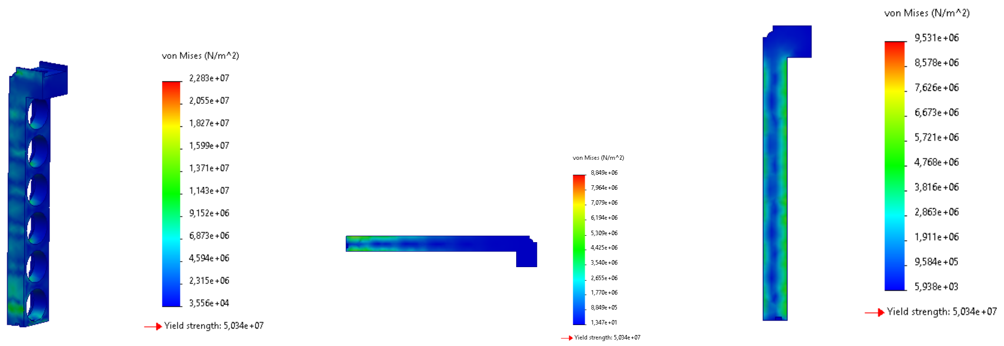
In the X direction the maximum tension obtained is $3.94MPa << 60MPa$.

In the Y direction the maximum tension obtained is $7.67MPa << 70MPa$

In the Z direction the maximum tension obtained is $35920Pa << 60MPa$

It can be concluded that under the circumstances predicted in the regulations the vertical support for the cells does not fail. Below it´s included some pictures of FEM simulations with the objective of validate and confirm the results calculated.

Figure 3: FEM simulations for vertical mount

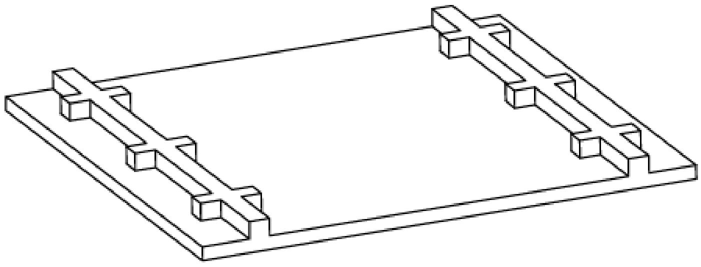


(a) X direction (b) Y direction (c) Z direction

2 Base Plate

The second part of the mounting is the base plate where the vertical support attach. The next image illustrates this base plate (figure 4).

Figure 4: Base Plate



2.1 Assumptions

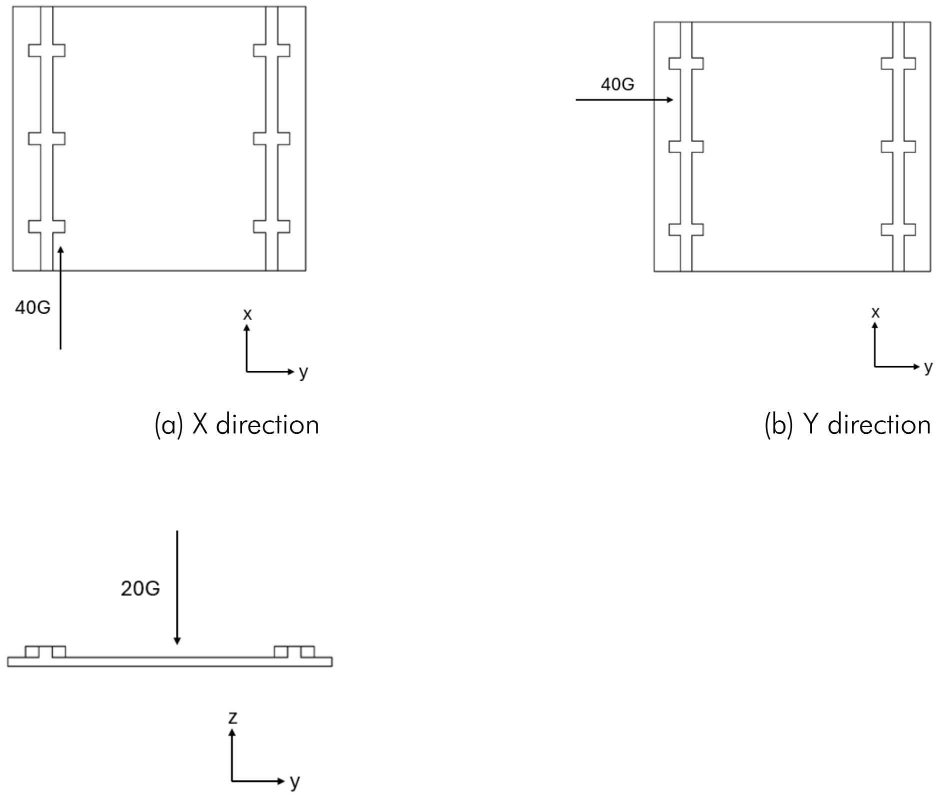
Given the geometry of the base plate, using a cross-shaped profile as a rail to attach the vertical supports, the main tensions registered are shear tensions.

For the X direction the tension is applied on the smaller profile of the cross shape. The load is evenly distributed to all this profiles (34). The force applied is the result of the mass of the cells and supports (the worst-case scenario).

For the Y direction there's also a shear tension applied along the main rails of the base plate. The load is distributed to the 2 rails. The worst-case scenario is considering the weight of the cells and supports.

For the Z direction it´s only verified a compression, result of the weight of the cells and supports. A schematic of the accelerations applied in each direction is shown in figure 5.

Figure 5: Accelerations Schematics



(a) X direction

(b) Y direction

(c) Z direction

2.2 Calculations

Equations used for X direction:

$$\tau = \frac{F}{A} \tag{5}$$

Where:

- $F = ma = [(17 \cdot 6 \cdot m_{cell}) + (17 \cdot 2 \cdot m_{mount})] \cdot 9.8 \cdot 40 = 17059.8N$ is the force applied
- $A = 9 \cdot 3 \cdot 17 \cdot 2 = 918mm^2$ is the area the shear occurs (from the dimensions of the plate)

Equations used for Y direction:

$$\tau = \frac{F}{A} \tag{6}$$

Where:

- $F = ma = [(17 \cdot 6 \cdot m_{cell}) + (17 \cdot 2 \cdot m_{mount})] \cdot 9.8 \cdot 40 = 17059.8N$ is the force applied
- $A = 3 \cdot 396 \cdot 2 = 2376mm^2$ is the area the shear occurs (from the dimensions of the plate)

Equations used for Z direction

$$\sigma = \frac{F}{A} \tag{7}$$

Where:

- $F = ma = [(17 \cdot 6 \cdot m_{cell}) + (17 \cdot 2 \cdot m_{mount})] \cdot 9.8 \cdot 20 = 8524.9N$ is the force applied
- $A = 3457.2 \cdot 6 = 20743.2mm^2$ is the area of compression (from the CAD model)

2.3 Results

In the datasheet for PETG, the shear strength is $60MPa$.

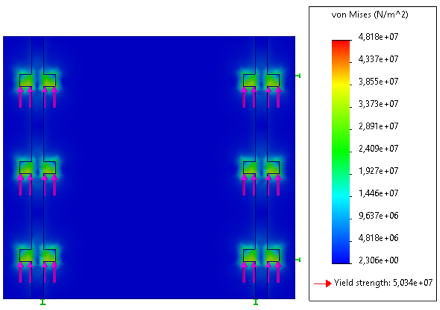
In the X direction the maximum tension obtained is $18.6MPa << 60MPa$

In the Y direction the maximum tension obtained is $7.18MPa << 60MPa$

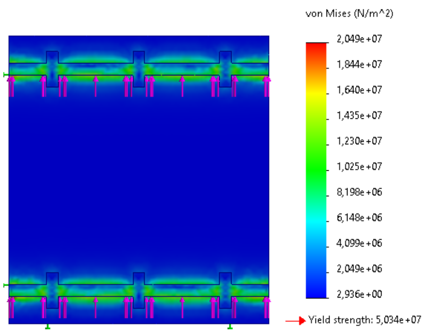
In the Z direction the maximum tension obtained is $0.41MPa << 60MPa - (compressive - strength)$

From this results, under the circumstances predicted in the regulations the base plate that supports the mounting for the cells does not fail. Below it´s included some pictures of FEM simulations with the objective of validate and confirm the results calculated.

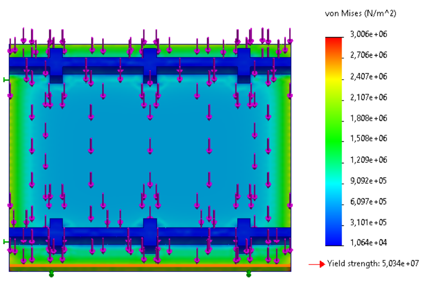
Figure 6: FEM simulations for base plate



(a) X direction



(b) Y direction



(c) Z direction

3 Conclusion

The results calculated analytically, validate our design, has the ,maximum tensions achieved in every direction and with the accelerations imposed by the regulations, are below the maximum tension strengths of the material. The simulations conducted in FEM, also confirm this results, because they don't reveal points of higher stress and failure of the structures.

Overall we can claim that our design for the cell mounting is valid under technical regulations.