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Getting the Delfi-PQ Ready for Multiple Launch Options

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PocketQubes represent a new type of cube-shaped platforms with dimensions of 50x50 mm and mass of 250 g. Just like the CubeSats, these platforms are also split in units which are referred to as 1P. The Delft University of Technology has been working on Delfi-PQ, a 3P PocketQube with the dimensions of 50x50x178 mm. This miniaturized size brings its own challenges on every subsystem. In this paper, structural design, integration and kill switch mechanisms will be explained.

Key Words: PocketQube, Delfi-PQ, AIT, launch loads

1. Introduction

The idea of this new form factor was first presented and proposed in 2009 by Prof. Robert J. Twiggs in collaboration with Morehead State University (MSU) and Kentucky Space. As first showcased, the so called PocketQube represents a cube-shaped platform of 50x50x50 mm with an approximated mass of 250 g. The first launched PocketQubes were launched through the UniSat5 mission.[1,2]

The first revision of the standard published in July 2018 comprises the harmonisation in dimensions between the main players within the PocketQube Community: Delft University of Technology, Alba Orbital and Gauss Srl. The aim of the published document is to converge towards common numbers and interfaces for a PocketQube platform.[3]

Delfi-PQ (see also Fig. 6) is the first PocketQube developed by the Delft University of Technology, with the aim to set a mechanical standard for this type of satellite and flight test the structure as well as validating in flight the designed and developed core bus.[4]

2. PocketQubes Deployment

Unlike CubSats, PocketQubes are held and pushed from their sliding backplates. In Figure 1, Alba Orbitals 6P PocketQube deployer is shown and the sliding backplate is visible on the edge of the mock up satellite which is inside the deployer. When PocketQubes are stacked up in the deployer, their backplates are the only contact surface in between them. The sliding backplate dimensions are 58x192 mm, according to the standard (see Fig. 2, showing the Delfi-PQ backplate). The standard states that a PocketQube should provide a contact surface of 21.5mm from both sides of the sliding backplate along the X-axis, on the +Z surface.[3]

Fig. 1. Alba Orbital 6P PocketQube deployer.[5]

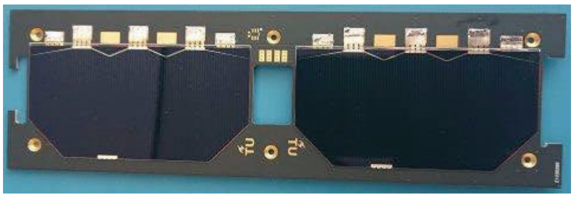

Fig. 2. Engineering model of the Delfi-PQ sliding backplate.

This is to make sure that when satellites are stacked on top of each other, deployment switches can be pressed. The -Z direction, on the right side of the sliding backplate, there is another cut out for the deployment switches. Detailed information can be found in the PocketQube standard.[3]

3. Structure and Integration

A PocketQube has a form factor of 50x50x50 mm: this is an extremely confined volume for a spacecraft which needs to have the bare minimum subsystems such as: EPS (including solar

Fig. 3. Partially integrated structure.

panels), battery, and communications. Considering the thickness of the solar panels and some integration margins (4 mm on each side), the board size has been standardized to 42x42 mm.[3)] When a direct satellite structure is designed, this will consume at least 1 mm on each side. In order to save internal volume and mass, structural ribs have been suggested instead of a complete satellite structure nd this approach has been tested in to show its feasibility, challenges and advantages.

3.1. Delfi-PQ Structure

The first version of the structure consists of 12 metal parts(3 different dimensions, 4 of each, used as corner pieces) and 4 solar panels. This system is extremely volume efficient. This system was manufactured to check its capabilities and Fig. 3 shows the integrated structure. Even without the subsystems, the alignment of the metal pieces and the solar panels is not easy. During integration, when spacers are also included, equalizing the height of every corner and aligning the structural parts with the solar panels requires multiple trials and errors, being quite time consuming. This approach was discarded due to its integration challenges and lack of stability. It can be feasible for a 1P PocketQube, but for 3P it is not recommended.

The second and current version of the Delfi-PQ structure mainly consists of 3 metal parts (Fig. 4) acting as structural ribs and 4 solar panels. This system is relatively stable and easier to integrate. Without the integration of the antennas, whole satellite can be assembled in 28 minutes.

3.2. Delfi-PQ Integration

The very confined volume limits the ability to move freely inside the satellite during its assembly. This mainly causes a problem when the solar panels are being integrated into the satellite and connected to the electrical power system. In order to make integration easier and reduce the number of running wires, spring loaded connectors have been placed on the battery system (Fig. 5).[6)] There are 8 spring loaded connectors, 2 on each side. On every side, one of the connectors is for communication and the other one is for power connection. On every solar panel there are 2 sets of 3 contact pads for these spring loaded connectors(Fig. 5).

The inhibit switch connections might be also implemented using wires but this would complicate integration even more: they have been replaced by locating the battery, the power system and antenna deployment board (which is the system handles the antenna deployment and located in the bottom side of the satellite,) on top of each other and directly connected. This extra connector consists of 7 signals, 4 for the inhibit switch control signals, 1 for battery charging, 1 for battery negative and 1 for power system ground. Functionality and location of these switches are explained in Section **4.2.**.

Figure 6 shows the integrated system with an RF measurement board on top (these connectors were used for RF performances characterisation and will not be used in-flight).

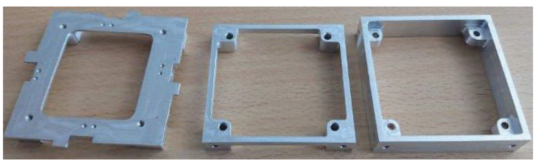

Fig. 4. Structural elements; from left to right: top, middle, bottom.

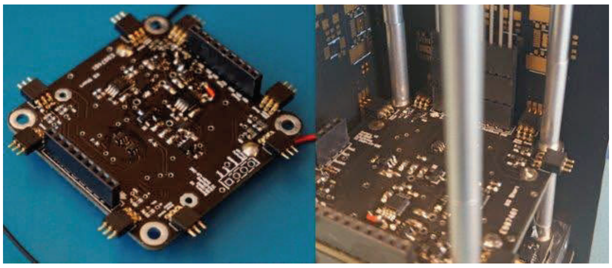

Fig. 5. Left: Battery subsystem of the Delfi-PQ with a pair of spring loaded connectors on each side; right: integrated battery system with contact pads for the spring loaded connector.

4. Deployer Electrical Interface

Currently there are no official documents for PocketQube electrical interfaces: the standard only mentions the possible locations for kill and deployment switches but not the inhibit switches. As a result, even tough they are required for CubeSats, no specification was available for PocketQubes: to solve this, references[7,8)] were taken as guide. The electrical interface of Delfi-PQ has been designed with respect to these guidelines in order to be compatible for the ISS (International Space Station) deployments.

4.1. Inhibit&deployment switch and Remove Befor Flight requirements

Both of the documents[7,8)] state that a CubeSat shall have at least 3 inhibit switches. Locations of the inhibit switches for both of the documents is shown in Fig. 7 which also includes the suggested deployment switch and RBF (Remove Before Flight)

Fig. 6. Delfi-PQ bus subsystems integrated.

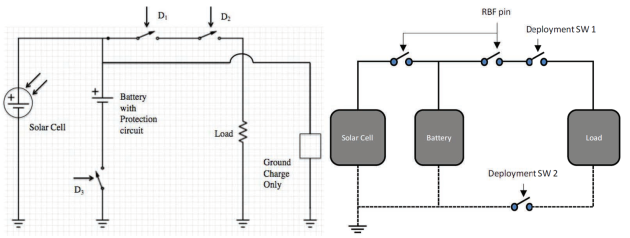

Fig. 7. Inhibit switch location; left: NanoRacks CubeSat deployer interface definition[8] and right: JEM payload accommodation handbook, small satellite deployment interface control document.[7]

pin connection to inhibit switches. JEM states that the satellite shall have three deployment switches, or two deployment switches and one RBF pin and NanoRacks states that the satellite shall have three deployment switches and shall have a RBF or ABF (Apply Before Flight) pin. Each deployment switch shall not generate more than 3 N[7,8] of force in pressed configuration.

4.2. Delfi-PQ inhibit and deployment switches and RBFs

Delfi-PQ consists of 4 inhibit switches, 2 RBFs and 2 deployment switches. 2 of the inhibit switches are located in the EPS and the other 2 are in the battery system (Fig. 8). The EPS inhibit switches are connected to one of the deployment switches and to one RBF. The battery systems inhibits switches are also connected in the same configuration as in the EPS, to a dedicated deployment switch and an RBF.

Each deployment switch on Delfi-PQ generates a force of $0.7\ N \pm 0.5\ N$.[9]Worst case switches will create a force of 1.2 N which is still below the limits stated by the documents. In Figure 9, 2 deployment switches are shown which are located in between the cutout. Same board also includes the 2 RBF jumper connections which are on the far side of the board(top right and top left of Fig. 9. For table top testing, deployment switches are directly soldered on to the board but in flight configuration there will be 1 mm spacers below them so that switches can be in contact with the pusher plate or the satellite below. A possible problem caused by the deployment switches is that, if they do not have the same force, the satellite might spin with respect to difference in the generated forces upon deployment.

4.3. Long term battery voltage during storage

The Delfi-PQ battery subsystem consists of 2 lithium-ion battery cells (750 mAh each) connected in parallel. The inhibit switches are normally pulled up to ensure that the satellite will start working after the deployment. These pull-up resistors are consuming extra power when the satellite is stored. During storage and launch, batteries should be kept around 3.6 V to ensure minimal aging. The satellite, after integration in the deployer, might have to wait for a long time (even up to 1 year)before launch with minimal maintenance possible. To make sure the Delfi-PQ battery system will still be functional after the storage phase without any additional charging, one set of batteries has been connected to the deployment switches and RBF switches to verify the battery self discharge at ambient temperature. Each battery cell voltage is being measured for more than 6 months and Fig. 10 shows the voltage level over time. At the beginning of the graph, battery cell voltages were not the same since the batteries were not equalised, and this small difference is still visible but over time this reduced and it is not visible anymore towards the end of the measurements.

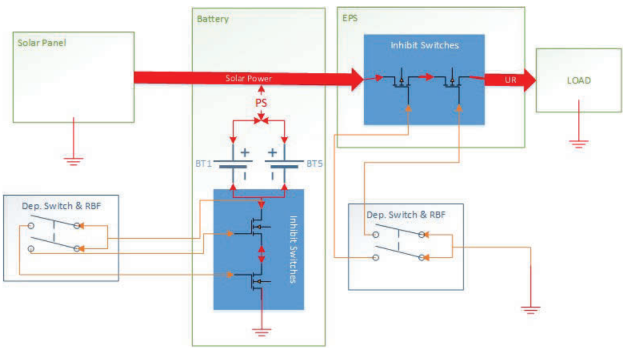

Fig. 8. Delfi-PQ inhibit switch locations and deployment switch and RBF connections.

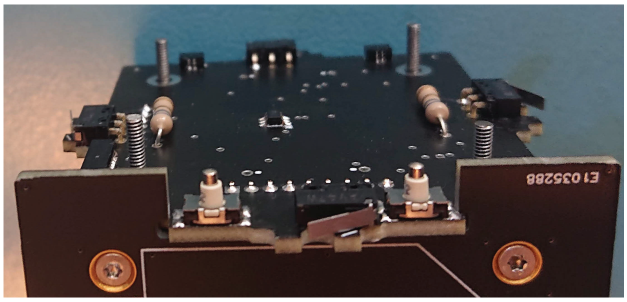

Fig. 9. Delfi-PQ deployment switches(plunger switches), antenna deployment detection switches(one of each side) and 2 RBF pin(jumper) connectors on the engineering model.

5. Vibration Analysis

To validate the design with respect launch conditions, vibrations analysis have been carried out. Two different cases have been investigated: one with the satellite 55% empty (406 g total mass, consisting of only the core subsystem) and the other is one with the satellite 30% empty (453 grams, with two additional subsystems/science units as in Fig. 11). This section includes the information related to the satellite model and results of: natural frequency analysis, acceleration analysis, random vibration analysis, sinusoidal vibration analysis and shock analysis. All of the analysis have been repeated for all directions (X-Y-Z). In all of the results, the 55% empty satellite is referred as model V00-00 and 30% empty satellite is referred as model V00-01.

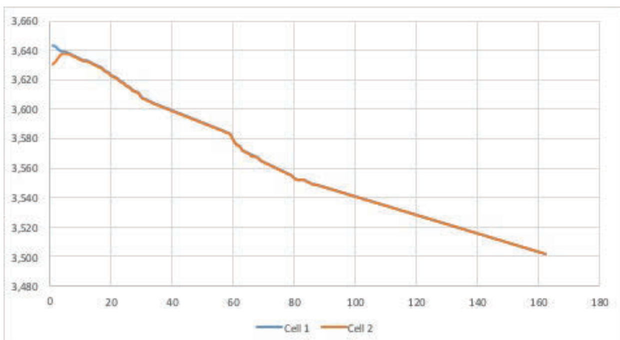

Fig. 10. Delfi-PQ battery system self-discharge.

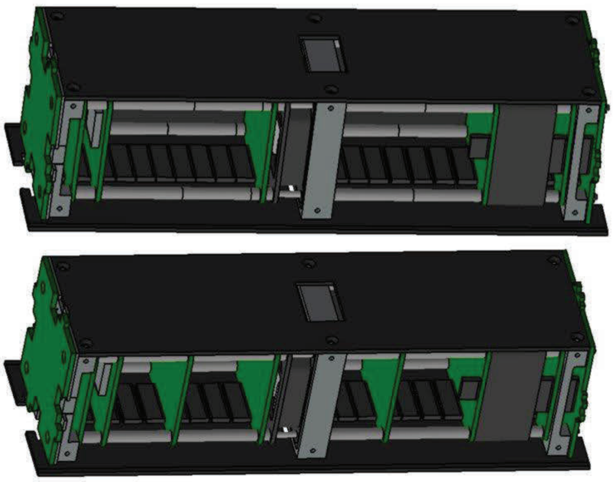

Fig. 11. Top: model V00-00, bottom: V00-01 model.

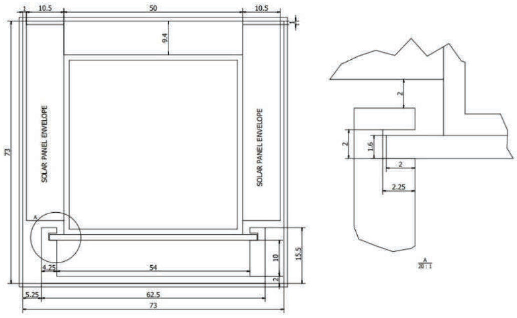

Fig. 13. Alba-Pod cross section[5)]

Table 1. Models natural frequencies.

Model	V00-00 [Hz]	V00-01 [Hz]
First	728.07	864.49
Second	866.22	884.72
Third	887.81	891.627
Forth	896.30	1676.97
Fifth	2010.65	1908.23

5.1. Models and loads

First of all, the models have been simplified in order to reduce the required processing power and time. This have been achieved via removing the antennas and removing the screws. Instead of screws, welded contacts have been given. General contacts of the subsystems are given as bi-directional type, because they are pressed by the spacers and by the structural parts, from +Z and -Z directions. In Fig. 12 each color represents a different material, turquoise is used for FR4, dark red for Aluminum, green for Copper and pink for plastic.

The satellites have been fixed with respect to PocketQube deployers: the sliding backplate is being fixed by its +X and -X surface where it will clamp the system for 2 mm along the Z axis.

5.2. Natural frequency analysis results

As seen in Table 1, natural frequencies are sufficient with respect to JEMs[7)] which requires it to be more then 100 Hz, and QB50 requirements[10)] which requires it to be more then 90 Hz. Smallest natural frequencies even for both of the models are still more then 700 Hz.

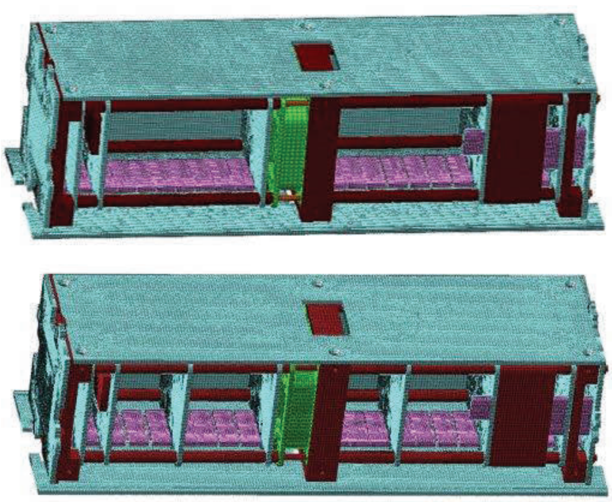

Fig. 12. Model Meshes.

5.3. Acceleration Analysis

Acceleration analysis have been done with an acceleration of 18.1 g.[7)] With respect to results in Fig. 14, 15 and 16, the satellite satisfies the requirements from QB50[10)] and JAXA.[7)]

5.4. Random vibration analysis

In Table 2, the profile for the random vibration is given.[10)] RMS value 8.03 g and duration is 120 seconds. With respect to analysis results, the maximum stress is less than yield stress (Fig. 17, 18, 14). As a result, satellite satisfies the requirements of QB50,[10)] Jaxa[7)] and PSLV.[11)] But further analysis needs to be done with respect to GEVS, cause it has the highest RMS value (14.1 g) for the qualification model.[13)] This is not necessary but it will prove that the satellite is strong enough and can be used without causing any problems.

5.5. Sinusoidal vibration analysis

In Table 3 the sinusoidal vibration profile is given.[10)] The satellite's first natural frequency is higher than 125 Hz as a result of this minimum stress and displacement are observed (Fig. 20, 21, 22).

5.6. Shock analysis

In Table 4 shock profile that is used for the analysis is given.[10)] In Figures 23, 24 and 25 displacements are reaching almost 2 mm. This value is too high due to profile the profile suggested by the QB50 but Nanoracks and Jaxa does not require the shock tests. Even though the stress is less than the yield stress of FR4, this might cause cracks on the solar cell.

Table 2. Random vibration profile.

Direction	Frequency [Hz]	Amplitude [g^2/Hz]
X,Y,Z	20	0.009
X,Y,Z	130	0.046
X,Y,Z	800	0.046
X,Y,Z	2000	0.015

Table 3. Sinusoidal vibration profile.

Direction	Frequency [Hz]	Amplitude [g]
X,Y,Z	5	1.3
X,Y,Z	8	2.5
X,Y,Z	100	2.5

Table 4. Shock profile.

Direction	Frequency [Hz]	Spectrum [g]
X,Y,Z	30	5
X,Y,Z	100	100
X,Y,Z	700	1500
X,Y,Z	1000	2400
X,Y,Z	1500	4000
X,Y,Z	5000	4000
X,Y,Z	10000	2000

This have been done in order to show every aspects of vibration testing.

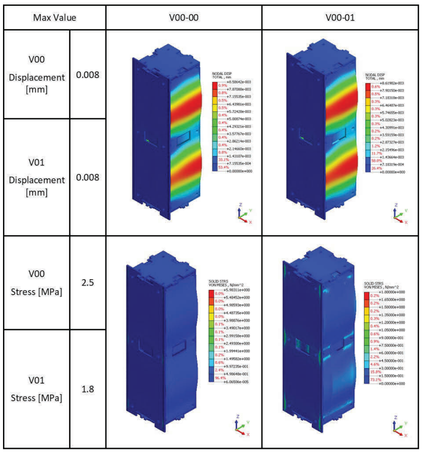

Fig. 14. Acceleration analysis results for X direction.

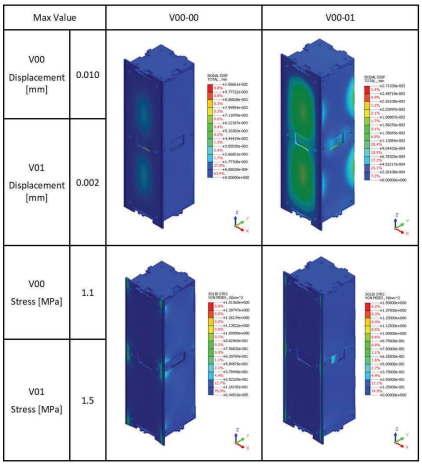

Fig. 15. Acceleration analysis results for Y direction.

6. Conclusion

In this paper the structural design, integration, electrical interface and vibration analysis of Delfi-PQ have been presented. A new version of the structure needs to be designed in order to make the integration easier. Electrical interfaces of the satellite with respect to NanoRacks and JAXA have been designed and showed to be compliant. A vibration analysis has been performed and it shows that during launch, shock levels on solar cells might be too high and will require further attention. In addition to that, GEVS[13] or VEGA[12] loads were too high for the system and will require future work. GEVS levels are considered a worst case for all launch vehicles and this, ultimately,

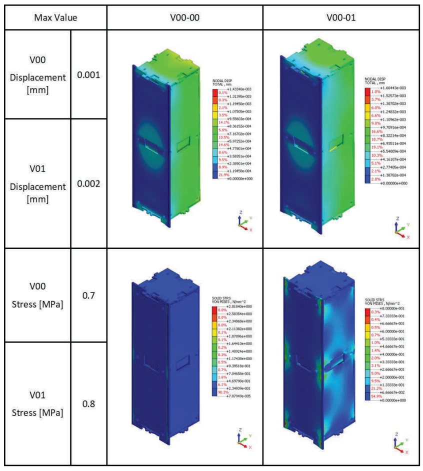

Fig. 16. Acceleration analysis results for Z direction.

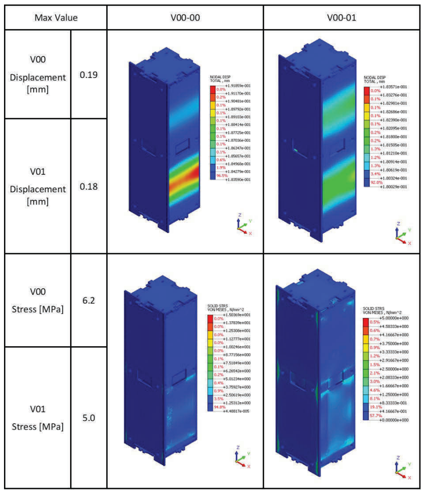

Fig. 17. Random vibration analysis results for X direction.

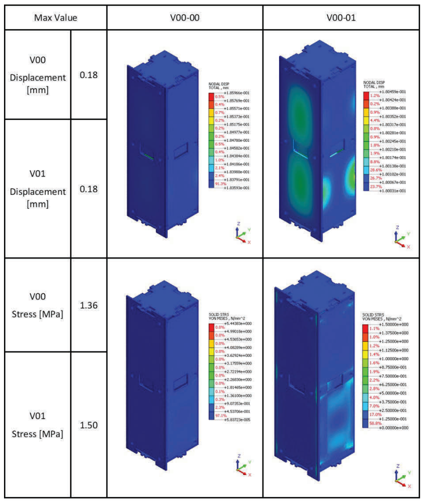

Fig. 18. Random vibration analysis results for Y direction.

will guarantee the satellite can be launched on all the current available rockets.

Acknowledgments

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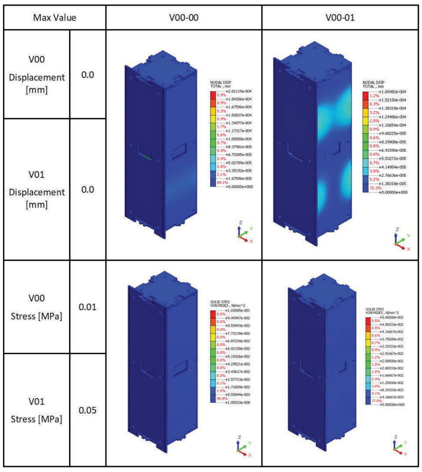


Fig. 22. Sinusoidal vibration analysis results for Z direction.

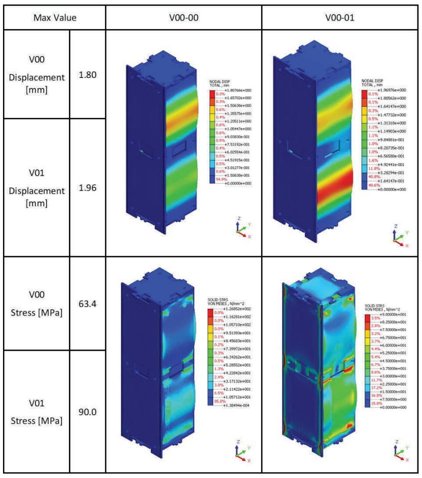


Fig. 23. Shock analysis results for X direction.

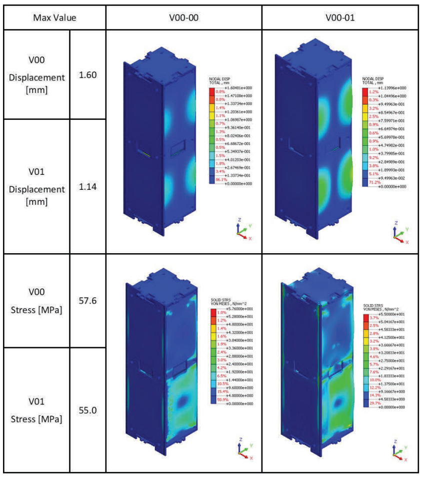
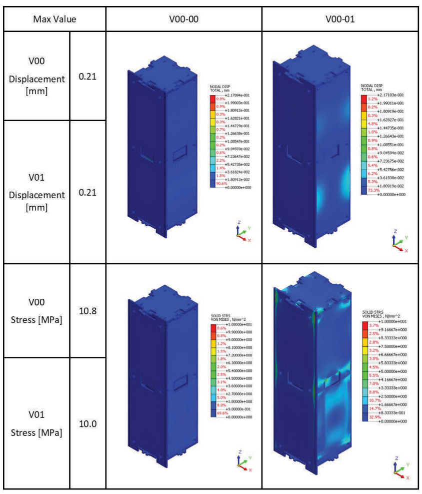


Fig. 24. Shock analysis results for Y direction.



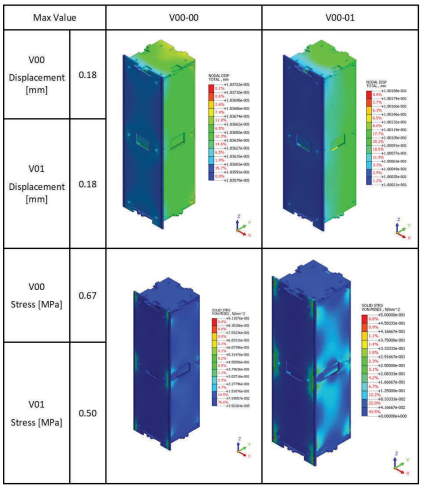


Fig. 19. Random vibration analysis results for Z direction.

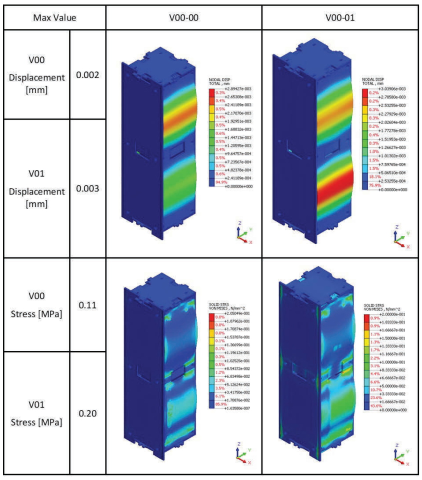


Fig. 20. Sinusoidal vibration analysis results for X direction.

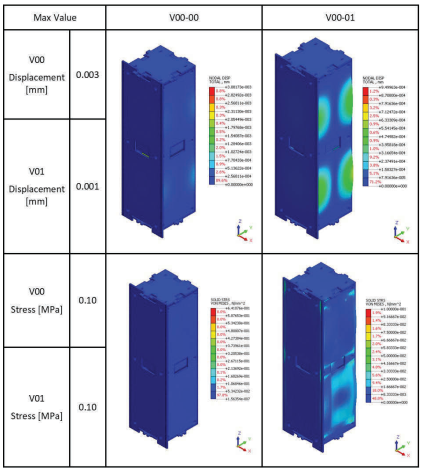


Fig. 21. Sinusoidal vibration analysis results for Y direction.

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