DESIGN AND TESTING OF A SAMPLE CONTAINER TO PRESERVE ROCK CORES FOR PROPOSED MARS SAMPLE RETURN

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ABSTRACT

As outlined by the Science Definition Team for NASA's proposed Mars 2020 rover mission, a long-term Mars Sample Return program would be a multi-step process designed to collect, cache, retrieve, and return Martian rock samples in metal tubes. In order to maintain the samples' scientific value, the seal used in the tubes must maintain cleanliness and seal integrity through events which may include launching off of the Mars surface by a Mars Ascent Vehicle and landing on Earth's surface at high-gravity force. Testing hardware was designed using computer-aided design software to fit the sample tubes for vibration and shock tests to validate a prototype sample tube-sealing method to Mars Science Laboratory qual/protoflight level for future sample return missions. Assembly and testing procedures were written to carry out the tests. Helium leak-rate data were collected on four different sealing methods before and after each characterization test. The seals were tested on a vibe table to simulate lift-off and then dropped from a drop tower at 3,500 G to characterize a high-gravity landing on solid earth. The aim of this task is to test which sealing method could best maintain a leak level of below 1×10^{-8} atm·cc/sec He. Details of the project will be used to write requirements on preserving the core samples.

INTRODUCTION

From time immemorial, philosophers and scientists have been attempting to find the origin of life. The Mars 2020 rover could play a scientific part in this search by bringing back samples of Martian rocks for laboratory analyses to determine if there ever was life on Mars. The Mars 2020 Science Definition Team (SDT) outlined a mission concept for the proposed Mars Sample Return (MSR) that includes "acquiring a diverse set of samples intended to address a range of Mars science questions and storing them in a cache for potential return to Earth at a later time." In anticipation of NASA's approval of the MSR mission, four sealing designs have been chosen to go through flight-like testing to select the best sealing method for bring rock samples back to Earth.

The proposed MSR would involve four discrete steps for returning rock samples; first, the Mars 2020 rover would drill rock cores and place them in a cache, which would be left on the surface of Mars for about ten Earth years until the second mission (the proposed Mars Ascent Vehicle, or MAV) lands on Mars for the retrieval of the cache; then, the MAV would launch the cache into Martian orbit where an orbiter would catch it; the orbiter would then send the cache to Earth in the Earth Entry Vehicle (EEV), which would hard-land in Utah Test and Training Range, on its soft clay surface.

During the entire mission, the seals that hold the samples in sample tubes must remain hermitically sealed to less than 10^{-8} atm·cc/sec

He. In order to test how well the four sealing designs work, flight-like conditions are simulated in laboratory settings then helium leak checked for hermeticity; some of the simulations include thermal cycle tests to replicate the temperature fluctuations on Mars, vibe tests to mimic lift off from the surface of Mars, pressure tests to simulate the flight from Mars to Earth, and shock tests to characterize hard-landing on Earth. Because there are limited previous studies on sealing methods, custom testing appliances were designed and manufactured specifically for conducting these tests. This research focuses on the design and manufacturing of the testing hardware.

BACKGROUND

During the previous summer (2012), shock tests were conducted by dropping a100-lb. aluminum shock block [Figure 1] containing rock samples from the height of 8 meters from a drop tower at Jet Propulsion Laboratory (JPL) to study how the cores, about the size of a chalk, fracture upon impact. The researchers recreated the same g-force previously achieved at Langley Research Center (Gershman et al.), where the necessary g-force for simulating the hard-landing of a EEV Drop Model at terminal velocity was found to be roughly 2,500 to 3,500 g. The shock block allows the rock cores to be dropped vertically, horizontally, and diagonally all simultaneously [Figures 2 and 3]. The block has a spherical bottom surface to prevent it from bouncing around on the edges upon impact, thus preventing the core samples from receiving multiple shocks.

This year, shock tests are being conducted using the same shock block, except now the focus of the research is on seal integrity as well as rock fractures. The clamshells used in 2012 [Figure 4] were designed to hold bare rock cores, and they fit inside the molds in the shock block in the three different orientations. The new clamshell design for this year allows room for the sample tubes containing the rock cores and seals to be inserted. The previous clamshell and the shock block dimensions became the starting point for this year's clamshell design. A vibe mount was then designed based on the new clamshell design.

DESIGNING THE CLAMSHELL

The shock block and the clamshell for bare rock cores were designed for conducting shock tests to study how rock cores fragment upon impact. The shock block holds up to three clamshells, each carrying rock core samples in vertical, horizontal, or diagonal orientations. The shock block is dropped from the height of 8 m to simulate hard landing at terminal velocity on Earth's surface at nearly 2,500 g. This year, the objective of the shock test includes evaluating the hermeticity of the seals as well as how the cores fracture.

The initial steps in designing the new clamshell focused on how the original clamshell and shock block work together. First, the clamshell mold inside the shock block was measured from the computer-aided design (CAD) that was made in SolidWorks. The old clamshell has a top and bottom pieces that clamp down on the rock cores; the new design uses the same method for holding the sample tubes. See Figure 5 for the final CAD.

The shock block is made of 6061-T6 aluminum alloy; the same material was used for both clamshell designs so that when they are assembled together, they essentially make one whole piece. There is a 0.50 mm margin around the perimeter of each clamshell to compensate for any manufacturing error, so that it fits inside the shock block without any problem.

Each rock core clamshell uses four 5/16-24 socket head cap screws (SHCS) to fasten onto the shock block, and the same screws are employed for securing the new clamshell; this way, the bolt pattern on the shock block can be used for any clamshell. To cut down on costs, the same screws (1/4-28 SHCS) used to fasten the top and bottom pieces together on the old clamshell was also used on the new clamshell.

Since the new clamshell will be testing sample tubes and not just bare rock cores, a great deal of consideration was made for accommodating the tubes. While three of the four sealing methods are plugs that go inside the test tubes, one of the seals incorporates a cap that goes around the outside. Therefore, the part where the caps are located must have a large enough clearance; a large section of the bottom part of the clamshell was cleared for this purpose. A Swagelok adapter that is attached at the other end of each sample tube facilitates connection to the helium leak detectors, and because it is much wider than the diameter of the tube, the length of the clamshell was cut to make room for the adapters.

The channels for the rock cores were widened in the new clamshell to house the sample tubes, and they were widened even more to compensate for possible manufacturing errors in carving out the channels; in fact, the test tubes themselves were manufactured with some inaccuracies in their diameters which varied as much as 0.50 mm. However, not all tubes are going to fit tightly when the channels are designed only for the widest possible tube, and they need to be clamped down tight enough so that they do not move around inside the clamshell while conducting tests.

In order to keep the tubes in place, the surface of the top piece of the clamshell that comes in contact with the bottom piece was shaved off about 0.50 mm. This way, the channels created by the top and bottom pieces do not make perfectly circular cylinders when they are assembled together and allows the top piece to clamp down on the tubes effectively.

While this solution successfully keeps the tubes in place, the tubes and rock cores cannot be clamped down too heavily to cause deformation or fracture and therefore possibly causing the seals to fail before any test is conducted. This problem is solved by inserting shims between the top and bottom pieces. Inserts of thickness 0.050 mm are added between the pieces until the tubes are clamped just enough to stay in place but not too much to where it damages the structure of the tubes. A simple procedure for using the inserts starts with using more than enough inserts (around 0.254 in.) and taking out each insert until the tubes are able to move just slightly, then tightening the ¼-28 screws until the tubes are secured in the clamshell.

After all of the technical details were considered in designing the clamshell, some thoughts were put into the manufacturing process of the clamshell. Sharp, tight corners can be difficult and time consuming using a computer numerical control machine, depending on the type of drill used or the size and shape of the area the raw material is placed during manufacturing. Therefore, to eliminate unnecessary detailing, tight inner corners were smoothed using fillets, cutting down on the production time and costs.

Another important and perhaps obvious aspect of working with sharp corners and edges is that they pose possible danger during assembly. Safety comes before anything else in any workplace, and this hazard was minimized by adding chamfers all around the edge of the clamshell. The final piece was then buffed to get rid of any bur.

DESIGNING THE VIBE MOUNT

Although the clamshell was designed primarily with the shock test in mind, there was a desire for also using it during the vibe test for economical and time-management reasons. The vibe mount holds the clamshell onto a vibe table, which vibrates in the vertical direction for a predetermined time duration, to simulate lift off from Mars' surface and the vibration caused by the rockets. The test evaluates how well the seals stay secure during lift off.

The same four 5/16-24 SHCS are used to fasten the clamshell onto the vibe mount. Although the mount can only hold one clamshell at a time, it also allows positioning the cores in vertical, horizontal, and diagonal orientations, similar to the shock block design. It is also made out of 6061-T6 aluminum alloy, so that the clamshell and vibe mount can be analyzed as one solid piece while conducting tests.

The weight and sturdiness of the vibe mount was a hotly debated issue during the design stage amongst the mechanical engineers and vibe test experts. The more the mount weighs, the sturdier the structure becomes, yet when it is too heavy, the vibe table cannot accurately reproduce the exact amount of g-force required to simulate lift off. The initial designs incorporated lightening holes to bring the weight down; however, it was eventually decided that the holes would make it too weak to hold the clamshell in place without wobbling around, which would create unwanted resonant frequencies in the vibration.

Instead, a heftier design was approved that has no lightening holes and includes a rectangular bottom surface that holds the vertical plate with gussets on either side [Figure 6]. The total mass of the vibe mount with the clamshell (without sample tubes) is 5.44 kg, and it meets the requirement necessary for our vibe table to replicate the lift off g-force. Figure 7 shows the three orientations of the rock cores on the vibe mount.

One oversight was detected when the vibe mount was placed on the actual vibe table, as its large footprint came into contact with the outer structure of the table, the part that does not vibrate. This error is rectified by placing another flat vibe mount (of 2.5 cm thickness) between the vibe mount and the table, thereby elevating the mount and eliminating contact between the mount and the outer edge of the table. The total mass of both mounts and the clamshell is 6.4 kg, still well under the maximum allowed by the vibe table. Some resonant frequencies are detected above 550 Hz; however, these frequencies do not affect the final results and objective of the vibe test.

FIGURES

Figure 1. The CAD model of the shock block.

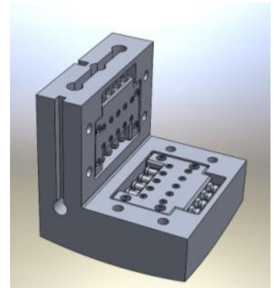

Figure 2. The inside of the shock block with the rock cores in the horizontal and vertical orientations.

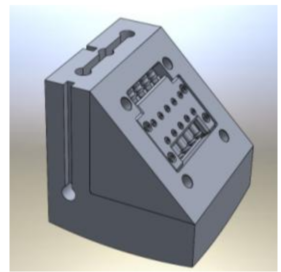

Figure 3. The CAD model of the shock block showing the third set of rock cores set in the diagonal orientation.

Figure 4. A clamshell holding the bare rock cores.

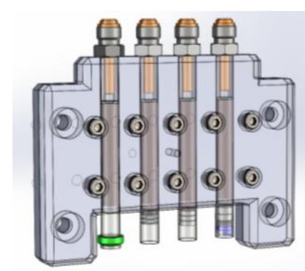

Figure 5. The top half of the clamshell and test tubes are shown transparent.

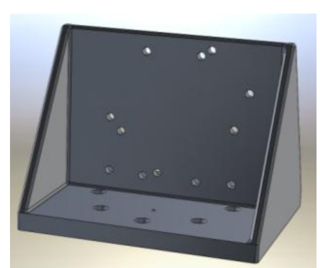

Figure 6. The vibe mount.

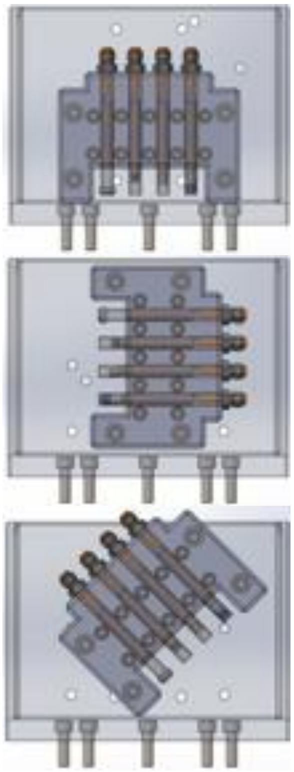

Figure 7. The rock cores mounted onto the vibe mount in vertical, horizontal, and diagonal orientations. The tests are conducted in one orientation at a time.

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