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| Condition(s) | Method |
| Vacuum of space | Vacuum chamber |
| Use a vacuum desiccator or air-tight chamber connected to a vacuum pump. |
| Temperature extremes | Use industrial freezer and thermal oven. Cycle between extremes. |
| Simulate thermal cycling in ANSYS or other software |
| Vibrations | Vibration generator with platform |
| Microgravity | Use a pendulum rig setup with overhead frame and cables (fishing line/thread) to suspend gripper |
| Atomic oxygen | N/A |
| Radiation and UV | Prolonged exposure to a UV source (UV lamp) |
| Darkness of space | Blackout enclosure (frame/box with blackout fabric) – (add camera) |

Vacuum of space: In space, there is an almost complete absence of atmospheric pressure known as vacuum. This condition can cause materials to outgas releasing trapped gases, leading to degradation of components. The lack of air pressure also alters how components interact as there is no medium for heat transfer through convection. Heat generated from the components can accumulate leading to overheating.

Whilst a vacuum chamber is the most ideal way of testing this condition, this is not possible due to lack of access. To simulate vacuum conditions, a vacuum desiccator or an air-tight chamber connected to a vacuum pump can be used. The desiccator allows for a controlled environment where air pressure can be reduced to mimic the vacuum of space. The gripper and/or components placed inside can be tested for structural integrity, outgassing behaviour, and material stability under these conditions.

Temperature extremes: Objects in orbit experience drastic temperature variations due to exposure to sunlight and shadow of the earth. These temperature extremes ranging from -100°C to +120°C in low Earth orbit can cause thermal expansion, contraction, and material fatigue.

Thermal cycling can be simulated using an industrial freezer for low temperatures and a thermal oven for high temperatures. By cycling components between these two extremes, the effects of thermal expansion and contraction can be observed. Additionally, thermal cycling simulations can be performed in ANSYS to analyse thermal stresses and material deformation over repeated cycles.

Vibrations: Components are subjected to intense vibrations caused by rocket engines and aerodynamic forces during a spacecraft’s launch. These vibrations can loosen bolts, cause material fatigue, or misalign components.

Vibrations can be modelled using a vibration generator with a platform. The gripper is securely mounted on the platform, and vibration profiles are applied to mimic launch conditions. Various profiles including sinusoidal and random vibrations will be tested in the range of 0–2000 Hz [1]. This method will help identify weak points and ensures that all components remain functional under vibrational loads.

Microgravity: The gripper in low earth orbit (LEO) acts as an object in free fall causing weightlessness effects. Gravity in LEO acts at approximately 88% of its strength on earth [2]. As the gripper and debris are in the weightlessness environment of orbit, they do not experience the downward force of gravity and instead float freely. There is no gravitational force to help stabilize components or grip objects naturally therefore precise control is essential.

A pendulum rig setup can be used where the gripper is suspended using lightweight cables attached to an overhead frame. This allows it to swing freely with minimal resistance, mimicking the absence of gravity. This method reduces the influence of gravity along certain axes, helping to observe how the gripper will function in space albeit it is not a perfect microgravity environment.

Atomic oxygen: Atomic oxygen (AO) is the highly reactive form of oxygen found in low Earth orbit. It reacts with and erodes surfaces of polymers and unprotected materials, leading to material degradation. Due to budget constraints and inaccessible facilities, this condition will not be able to modelled.

Radiation and UV: Intense UV radiation from the Sun can degrade materials causing discoloration and embrittlement. Radiation, such as cosmic rays and solar particle events, can damage electronics and weaken materials over time. Radiation from cosmic rays and solar particle events will not be possible to model.

The effects of UV radiation can be simulated by exposing components to a UV lamp for prolonged durations. UV lamps mimic the intensity and wavelength of solar radiation, allowing for accelerated aging tests. Materials and coatings can be evaluated for their resistance to UV-induced damage.

Darkness of space: Objects in space regularly pass into the Earth's shadow leading to complete darkness. This condition affects sensors, cameras, and thermal performance, as there is no sunlight to provide illumination or warmth.

A blackout enclosure is created using a frame or box lined with blackout fabric ensuring complete darkness for testing. A (night-vision) camera can be added to monitor the gripper’s operation in low-light conditions.

References:

[1]

“Vibration Testing of Small Satellites.” Accessed: Feb. 6, 2025. [Online]. Available: <https://www.instarengineering.com/pdf/resources/Instar_Vibration_Testing_of_Small_Satellites_Part_5.pdf>

[2]

NASA, “What is Microgravity? - NASA,” *NASA*, Feb. 13, 2009. <https://www.nasa.gov/centers-and-facilities/glenn/what-is-microgravity/>

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