Shape Memory Alloy Based Hard Docking Mechanisms for two-stage CubeSat Docking

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On-orbit docking methods already in use in larger spacecraft, such as the ISS, have a long history and a high TRL; however, on-orbit docking systems for small satellites have yet to be evaluated in a space environment. Currently, no docking mechanisms involve an airtight seal for transferring materials from one small spacecraft to another to permit on-orbit servicing. Instead, most proposed docking techniques for CubeSats use a single phase involving magnetic force (soft capture). Using magnets for docking is undesirable, as they cause Electromagnetic Interference (EMI) when one CubeSat's electronics moves in the presence of a docking magnetic field. In addition, the electromagnets used for docking consume large amounts of power to maintain a docked configuration and require complex control algorithms to perform a successful dock. The electromagnetic force between the two CubeSats alone may not be enough to support an airtight seal for material transfer, hence calling for a mechanical latching system as a second stage in docking.

This paper discusses using geometric pairs of docking adapters with a second stage involving Shape Memory Alloy (SMA) spring-loaded latches. The geometric pair docking adapters are modified cones and probes which ensure proper mating irrespective of the x-y translational and z-rotational misalignment. They possess mechanical latches and slots on their faces, loaded by SMA springs. As the first docking stage is complete, the latches automatically lock onto the slots, creating the second stage hard dock without electrical power. The SMA spring contracts and releases the hard dock on command, and the two docking smallsats may use CubeSat propulsion to maneuver away from each other.

Based on the 3D simulation results and the analytical calculations, prototypes are developed for testing in simulated conditions in the laboratory. Ground-based systems such as 6-DOF robotic arms mimicking the ADC systems of the spacecraft and air tables to simulate the frictionless environment of space will be used to validate the designs. We aim to demonstrate a successful docking scenario between two CubeSats equipped with metal 3D-printed prototypes of our docking adapters. In addition, we aim to perform experiments to measure the precision, repeatability, and reliability of the SMA springs used in the adapters and arrive at requirements for space qualification of the mechanism. We further discuss the power consumption and optimization of the mechanism's mass, power, and volume.