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# SCALING EFFECTS IN MINIATURIZATION OF REACTION SPHERES

**Abstract**

In past decades, reaction spheres were proposed as innovative momentum exchange actuators. Compared to conventional reaction wheels, reaction spheres perform $4\pi$ rotations and provide control torques about three principle axes. Therefore, a single reaction sphere is sufficient for three-axis stabilizations. Currently, a majority of the reaction spheres are at the technology readiness level of 3 or 4 and prototypes are normally developed for 50 kg-class spacecraft. Since the motivation of replacing reaction wheels with reaction spheres stems from the limited volume and power budgets of small spacecraft such as nanosatellites, miniaturization of reaction spheres is expected.

In this paper, several existing prototypes of reaction spheres are miniaturized with a scaling factor, making their physical dimensions suitable for CubeSats. In the miniaturization, parameters of involved windings are adjusted properly, due to limits in manufacturing technologies. However, thermal expansions and scaling effects on the properties of materials are neglected for simplification. Based on the published models and experimental data of the prototypes, performances of the miniaturized reaction spheres are estimated. Relations between the estimated performances, such as output torque per power, and the scaling factor are investigated. Through comparisons of the scaling characteristics of different prototypes, designs based on permanent magnets demonstrate relative advantages in the miniaturization.

Meanwhile, with the study case of a LEO CubeSat, performance requirements of a single reaction sphere based attitude control system are defined. By integrating the scaled reaction sphere to the CubeSat, it is found that generating required outputs with the limited power budget is the main challenge. To improve efficiency of the miniaturized reaction spheres and make their applications to small spacecraft feasible, innovative designs of driving units as well as advances in superconductor and manufacturing technologies are required.