OPTIMIZING LABYRINTH SEAL GEOMETRY TO MINIMIZE LIQUID LUBRICANT EVAPORATION IN SPACE SYSTEMS

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KEYWORDS

Space tribology; Fluid lubrication; Experiments in tribology, Vacuum evaporation

ABSTRACT

Surface lubrication in space applications involves utilizing either solid or liquid lubricants, chosen based on specific boundary conditions. However, liquid lubricants are prone to vacuum evaporation in space environments, where ambient pressure is lower than substance vapor pressure. Determining evaporation rates, influenced by pressure and temperature is crucial for designing space mechanisms. Understanding oil evaporation in ultra-high vacuum is vital for predicting mission lifetimes and preventing critical subsystem contamination. Implementing labyrinth seals is crucial for mitigating liquid lubricant evaporation, ensuring optimal performance and long-term durability of space systems.

To address the challenges posed by liquid lubricant evaporation in space applications, we present a comprehensive approach. This approach involves novel measurement methodologies, theoretical analyses, molecular flow simulations, and experimental validations.

In our investigation, we utilized Monte Carlo simulations of molecular flow and mathematical particle tracing tools to understand how labyrinth seal geometry parameters impact evaporation rates and the transmission probability of evaporated molecules. These simulations provided valuable insights into the mechanisms governing liquid lubricant evaporation within labyrinth seals, allowing for effective optimization of seal design parameters and minimization of evaporation losses.

For experimental verification, we modified our existing vacuum evaporation measurement setup [1] to include labyrinth seal test samples (see Fig. 1). This modification enabled direct measurement of evaporation rates through controlled laboratory experiments. Through rigorous experimental validation, we aimed to refine and validate our simulation models, ensuring their applicability in real-world space environments.

Our testing results revealed a correlation between key geometry parameters of labyrinth seals, including length, width, grooving, and surface roughness, and the transmission probability of evaporated molecules traveling through the labyrinth. Proper optimization of these geometric factors and manufacturing methods can effectively minimize lubricant loss in spacecraft mechanisms, thereby mitigating the risk of contamination to surrounding satellite subsystems and prolonging the lifetime of space technology.

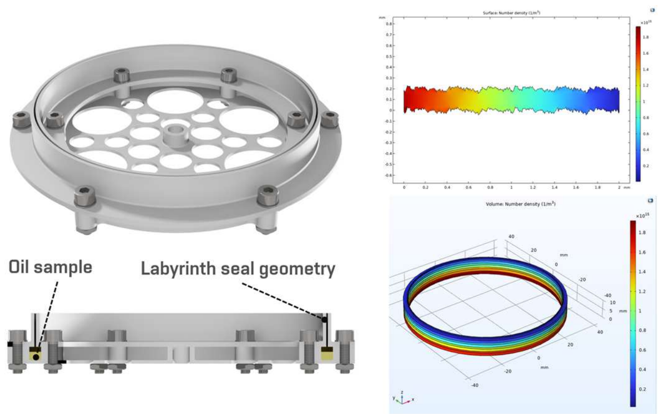

Fig. 1 Evaporation Test Rig and Molecular flow simulations

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