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Advanced Materials and Structures for High Temperature Applications (4)

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ADVANCED MATERIALS FOR THERMAL MANAGEMENT OF SUPERCONDUCTOR-BASED SPACECRAFT SYSTEMS

Abstract

The past years has seen a significant increase in traction on the use of High-temperature Superconductors (HTS) for spacecraft subsystems. However, in some particular use-cases, an advanced thermal management system is required to insulate the superconducting tapes from high temperature environments. Two such examples are HTS-based Applied-Field Magnetoplasmadynamic (AF-MPD) plasma thrusters, where the plasma can impose temperatures exceeding 2000K on the thruster electrodes. Similarly, the outer surface of a spacecraft is heated to temperatures as high as 1900K by plasma encountered during planetary re-entry. In the past, the use of conventional copper electromagnets has limited AF-MPD flight feasibility due to their significant mass and power consumption. The SUPREME (SUPerconductor-based Readiness Enhanced Magnetoplasmadynamic Electric-Propulsion) thruster replaces the copper electromagnets used in conventional AF-MPD thrusters, with HTS coils. The use of HTS greatly reduces the mass and power consumption of the electromagnets, whilst providing an increase in magnetic field strength, improving thruster lifetime and performance. The operational temperature of the HTS coils at 50K necessitates the use of a cryogenic system, and a thermal management system (TMS) that is capable of shielding the HTS coils from the high temperatures imposed by the thruster plasma plume. The TMS is designed to provide passive thermal control, utilising multi-material architectures with differing thermal and structural requirements. This approach is based on similar shielding solutions utilised for spacecraft re-entry in the past, and has applicability to another superconductor-based spacecraft subsystem, MEESST (Magnetohydrodynamic Enhanced Entry System for Space Transportation). This paper will address the key requirements for the individual material layers of the TMS, for both SUPREME and MEESST. Various material architectures are modelled and assessed according to their suitability to fulfil these requirements, and candidate multi-material architectures are selected for manufacture and testing. Key challenges associated with the TMS will be addressed, such as the insulation of a large thermal gradient over a short distance, the need to effectively manage significant quantities of heat generated by the thruster plume, and the internal stresses resulting from the differing thermal expansion coefficients of material layers during operation. The results will include the benchmarking and down selection of candidate materials for each layer of the TMS. Thermo-optical measurements will be used to characterize material properties at elevated temperatures. The results from the thermo-optical measurements will be used to develop detailed thermal and structural simulation and optimisation of the TMS on a 2D, axisymmetric basis.