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MULTI-OBJECTIVE DESIGN OPTIMISATION OF CUSPED FIELD THRUSTER FOR MICROSATELLITE PLATFORM VIA EVOLUTIONARY ALGORITHMS USING GPU-BASED SURROGATE PREDICTION

Abstract

Electric propulsion (EP) is a suitable propulsion technology for satellites and space missions, offering advantages over chemical propulsion in various aspects including fuel consumption and light weight. The Cusped Field Thruster (CFT), in particular, offers advantages from miniaturisation perspectives over other types of EP such as the Gridded Ion Thruster and Hall Effect Thruster, due to enhanced electron confinement owing to magnetic mirror and reduced particle loss effects at the dielectric wall. Particle-in-cell simulations have been performed for the selected design points identified in multi-objective design optimisation (MDO) studies for verification by accurately accounting for phenomena and performance losses that originate from uncertainties and complexities associated with the thruster design and physics. However, there still remains room to examine the optimal design configurations in the highly nonlinear problem in consideration of design criteria to fulfill mission requirements.

The present work aims to develop insights into the effects of thermal conditions on the CFT performance and physical mechanisms associated with optimal thruster design. The MDO study is conducted in a heuristic approach via evolutionary algorithms (EA), where individuals represented by the decision variables, i.e., anode voltage, anode current, mass flow rate and geometric configuration, are evolved over generations via genetic operations including crossover and mutation. It aims to simultaneously maximise 3 objective functions, namely, thrust, total efficiency and specific impulse, while satisfying the geometric and thermal constraints, which are based on the empirical models for a relevant class of electrostatic propulsion. Surrogate models based on meta functions including response surface model, artificial neural network and Kriging model are built using the archive of results from the power balance model (PBM) coupled with magnetic field simulation. Evolutionary optimisation is performed via EA incorporating surrogate prediction on GPU (graphics processing unit) in a highly parallel manner, which enables efficient evaluation of the objective and constraint functions for a substantially large population.

Consequently, the behavior of the performance parameters can be captured accurately in response to the decision variables. The physical characteristics are scrutinised by performing magnetic field simulation with PBM for representative optimum designs selected from the non-dominated solutions that constitute the Pareto optimal front. Variance-based sensitivity analysis of the MDO results is performed to identify influential design parameters on the thruster performance. In so doing, insights are gained into the key

design factors and underlying physics that play a crucial role in downscaling of CFT for microsatellite platforms while maintaining high performance.