

Thrust Production Mechanism of Magnetic Sail Spacecraft with Superconducting Coil

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In the past decades, a lot of new propulsion system concepts for deep space missions were proposed and intensively investigated. One of them is called magnetic sail propulsion. The thrust of magnetic sail is generated, by utilizing the interaction between the plasma-flow solar wind and an artificial magnetic field produced around the spacecraft. It can be said that the solar wind energy is converted to the thrust of magnetic sail, which generates continuous high thrust in the outward radial direction from the sun to possibly achieve short flight-time transfer to planets in the solar system.

The first magnetic sail concept was proposed by Zubrin and extended by Winglee by introducing the plasma injection to inflate the artificial magnetic field. In order to obtain a continuous and high thrust, the use of a superconducting coil for generating the artificial magnetic field is appropriate, since a strong and continuous electric current can be maintained in superconducting materials without heat loss. In this study, we focus on such superconducting characteristics as well as coil design parameters, and evaluate the thrust characteristics of magnetic sail spacecraft.

First, two-dimensional analytical method for magnetic sail thrust model was introduced by extending that by Spreiter and Briggs for the Earth's magnetosphere in the solar wind. In the proposed method, the boundary electric currents and the induced magnetic field around the coils are used to obtain the thrust of magnetic sail. With this method, we investigate the thrust characteristics of magnetic sail spacecraft taking the coil design parameters into account. Then, the effect of superconductivity on the produced thrust magnitude is evaluated by comparing the two-dimensional analytical model with the results obtained by the magnetohydrodynamic simulation. Finally, in the three-dimensional model, the quantitative relation between the thrust and coil parameters (i.e., dimension and mass) are discussed.

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