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OPTIMAL DESIGN OF CONDUCTION-COOLED SUPERCONDUCTING MAGNET FOR MAGNETO PLASMA SAIL

Abstract

Superconducting magnets can revolutionize space propulsion systems. The performances, e.g., acceleration and thrust to power ratio, of a magneto plasma sail and electric propulsion can be greatly improved with a superconducting magnet by generating a larger magnetic field with less power consumption and weight. The magneto plasma sail is a novel spacecraft propulsion system with higher specific impulse for future deep space explorations. The thrust of the magneto plasma sail is produced by the transfer of momentum from a solar wind plasma to a strong magnetic field generated by a High Temperature Superconducting (HTS) magnet installed in the spacecraft, and is proportional to the magnetic moment of the installed magnet. In order to obtain enough thrust to mass ratio, or acceleration, for space missions, the magnetic moment to mass ratio of the installed HTS magnet must be drastically increased. Our purpose is to develop a light-weight HTS magnet with a larger magnetomotive force and magnetic moment based on radiation and/or conduction cooling as a cooling system for the superconducting magnet.

For the optimal design of the HTS magnet for use in space, we analyzed the nonlinear current transport characteristics, thermal stabilities, and applied mechanical stresses of HTS magnets on the basis of a developed thermo-electromagnetic analysis method with taking into account cooling condition. Using the genetic algorithm and developed analysis method, we optimized the configuration of the HTS magnet at a specific constraint condition of the sail system to obtain as large magnetic moment as possible and clarify the obtainable propulsive force from the magneto plasma sail.

As an optimization result, we showed the difference between the optimal magnet design for terrestrial HTS applications and for the magneto plasma sail. We also revealed that a thin-walled racetrack magnet with a larger diameter can achieve the magnetomotive force at 2.0×10^6 A-turns and the magnetic moment at 3.0×10^7 A$\cdot$m^2 which were four times larger than that obtained from a previous study, with allowable stresses and high thermal stability for space missions. The analysis also estimated the adequate amount of a reinforcement material to sustain mechanical stresses applied to the HTS magnet, and evaluated the minimum required weight of the HTS magnet for the magneto plasma sail.

This study proves the possibility of greatly increasing the thrust to mass ratio of the sail system, and leads to realizing the world's first space propulsion system using an HTS magnet.