THRUSTING PERFORMANCE DEGRADATION CAUSED BY CURRENT LEAKAGE THROUGH PINHOLES IN ELECTRODYNAMIC TETHERS

Sven G. Bilén

Communications and Space Sciences Laboratory, Department of Electrical Engineering, The Pennsylvania State University, 315B Electrical Engineering East Bldg., University Park, PA 16802, U.S.A., sbilen@psu.edu

Electrodynamic tethers (EDTs) are being considered as method of in-space "propellantless" propulsion for spacecraft in low-to-medium Earth orbit. This propulsion is accomplished through the conversion of a magnetic force on a current to mechanical energy when electrical current flows through a conducting tether in the Earth's magnetic field. Depending on the direction of current flow, the force is either orbit raising or lowering. The electromotive force (emf) to drive current for orbit-lowering situations comes from the orbital energy of the spacecraft. For orbit-raising situations, an alternate energy source, such as from batteries or solar cells, must overcome the motional emf and reverse the direction of current flow. Tether current flow is enabled by collecting electrons from the ionosphere near one end of the tether and either injecting them back or collecting ions at the opposite end.

The ability to thrust via electrodynamic means is proposed for use in future missions and systems including MXER (Momentum-Exchange/Electrodynamic Reboost) tether transportation systems [1]. MXER systems promise fully-reusable in-space transportation infrastructure that will boost spacecraft and payloads from low-earth orbit altitudes to high-energy transfer trajectories [2,3]. The MXER concept combines the principles of momentum exchange, in which a rotating tether system quickly provides orbital energy to a spacecraft by picking it up from a low orbit and tossing it into a higher orbit, with electrodynamic-tether propulsion to make up for the lost orbital energy of the rotating tether system.

To meet MXER system requirements of long-duration and efficient electrodynamic thrust performance, the system requires a high-conductivity, high-strength, insulated tether that can operate reliably at up to several kilovolts of bias with respect to the surrounding plasma. Of particular concern is the fact that the tether will be exposed to the flux of micrometeoroids and orbital debris (M/OD) present in Earth orbit, and impacts by these particles will cause nicks and pinhole breaches in the tether's insulation. Even assuming that the pinholes do not cause significant arcing at the plasma–metal–insulator triple point, which is itself a concern [4], these breaches represent a loss mechanism for current flow along the tethers, decreasing thrusting performance. That is, the leakage current will grow steadily over time as the tether continually experiences M/OD impacts, and the performance of the electrodynamic-reboost tether system will degrade.

This paper discusses the physics of the current loss mechanism based on previous experimental modeling [5]of the small breaches, i.e., pinholes. It then develops several system-level studies on the performance degradation due to anticipated levels of leakage current, considering factors such as tether geometry and length, plasma density, magnetic field, and orbital velocity. Depending on what levels of performance degradation are acceptable, methods to mitigate against leakages are required.

REFERENCES

[1] G. Khazanov, E. Krivorutsky, and K. Sorensen, "Electrodynamic tether as a thruster for MXER studies," AIAA Paper 2005–4116, 2005.
[2] K. Sorensen, "Conceptual design and analysis of an MXER tether boost station," AIAA Paper 2001–3915, 2001.
[3] R.P. Hoyt, J.T. Slostad, and S.S. Frank, "A modular Momentum-eXchange/Electrodynamic-Reboost tether system architecture, AIAA paper 2003–5214, 2003.
[4] B. Vayner, J. Galofaro, D. Ferguson, and W. de Groot, "A comprehensive study of conductor–dielectric junctions in a low density plasma," AIAA paper 2000–0871, 2000.
[5] O. Kern and S. G. Bilén, "Model of current collection to small breaches in electrodynamic tether insulation," AIAA paper 2003–4947, 2003.