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A corrected tether-mission to Jupiter

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Abstract

A spacecraft slowly descending in equatorial orbit through the inner magnetosphere of Jupiter over a period of months would provide a wealth of knowledge through space and time resolved observations. An electrodynamic (ED) bare-foil tether has been proposed as allowing a spacecraft to attain a circular orbit below Jovian radiation belts and Halo ring (so as to then carry out scientific observations) using Lorentz drag on the current induced in the tether for orbit insertion, followed by a series of perijove passes to progressively lower the apojove. Accumulated radiation dose was reasonable when using a 50 km long tether. It was recently shown, however, that electron collection by the tether would then be in a relativistic regime. This yields a penetration depth in aluminum exceeding foil thickness. Reducing the length to 10 km is here proposed, followed by a reconsideration of the scientific mission objectives.

1. Introduction

Main issues facing missions to Jupiter are its intense radiation belts and deep gravitational well. All Jovian missions (*Pioneer* 10 and 11, *Voyager* 1 and 2, *Ulysses*, *Cassini*, and *New Horizons*) have been flybys with the exception of Galileo, which, anyway, was moved far from the planet surface following orbit insertion at $4R_J$, by rocket thrust applied at the first apojove, beyond $100R_J$. NASA's *Juno* mission is singular in that it will spend time close to Jupiter's surface, though just a few hours in each of its planned 32 highly-eccentric, 11-day *polar* (sneaking-under-the-Belts) orbits. Opposite all these missions, however, a spacecraft slowly descending in equatorial orbit through the inner magnetosphere of Jupiter over a period of months, after reaching below Belts and *Halo* Ring at around $1.4R_J$, would provide a wealth of knowledge through space and time resolved observations.

2. A tether at Jupiter

An electrodynamic (ED) foil bare-tether has been proposed as allowing a spacecraft to attain a circular orbit below Belts and Halo ring [1]. Lorentz drag on the passively induced current in the tether would first brake the spacecraft into a near-parabolic orbit with perifocus below $1.4R_J$, then progressively lower the apojove through a series of drag arcs at passes around the near-constant perijove. The weak plasma density in the lower magnetosphere of Jupiter makes a high number of passes necessary, which implies long operation and makes ED tethers the more mass-efficient as compared to rockets. Too many passes, however, may result in high belt-electron fluence and accumulated radiation dose, requiring heavy radiation shielding. Calculations in Ref. [1] suggest that a 50 km tether length L might get a spacecraft to a circular orbit below the Belts with reasonable radiation dose.

Both orbit-to-plasma relative velocity $\mathbf{v}_{rel}$ and magnetic field $\mathbf{B}$ are much greater at Jupiter than at Earth, leading to a further so motional field $\mathbf{E_m} = \mathbf{v}_{rel}\wedge\mathbf{B}$. A characteristic value for the full electromotive force, $\Phi_p = v_{rel}\, B\, L$, would reach near 0.25 MV for L = 50 km. Attracted electrons would then periodically arrive at the anodic tip of the spinning tether with moderately relativistic velocities. The orbital-motion-limited (OML) high-bias regime of cylindrical Langmuir probes was recently extended to the relativistic subregime [2]. The electron density in the sheath is enhanced over classical OML results, which may avoid electron trapping. Collected current, given by the law

$$I_{OML} = 2N_0RLec\,(1+\beta)^{1/2}[(1+\beta)^2 - 1]^{1/2} \qquad (1)$$

with $\beta \equiv e\Phi_p/m_ec^2$, exhibits enhancement over the OML law too.

3. Short tether requirement

The tether has a foil or thin-tape cross section because this maximizes its current-to-mass ratio. The tether in [1] was only 0.05 mm thick. The penetration depth of 0.2 MeV electrons in aluminum is about 0.25 mm [3], which is well over tether thickness. This suggests using a shorter tether, say L = 10 km, which reduces maximum electron energy to about 0.04 Mev, for which penetration depth is just 0.01 mm. Notice that the decrease in orbit eccentricity at every perijove pass is reduced along with the length. Capture by tether drag from a simple Hohmann transfer from Earth may now be impossible, and gravity-assist operations may be required.

The reduction in tether length will also require a greater number of perijove passes to finally get the spacecraft at the circular orbit below the Belts. This increases the radiation dose accumulated in the spacecraft over the entire operation, starting with capture. The figure presents the new accumulated dose versus perijove capture for both retrograde and prograde cases. Required number of passes and dose are naturally smaller for retrograde orbits; although such orbits have greater tether heating and bowing, this places no serious constraints due to the shorter length considered.

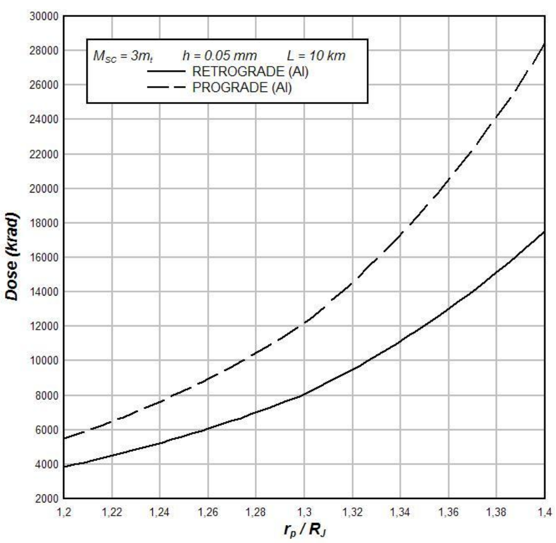

Figure 1: Accumulated radiation dose down versus normalized perijove radius to low Jovian orbit.

6. Conclusions

Tether length must be reduced from the originally suggested 50 km [1] to a tentative value of 10 km. This reduces penetration depth by attracted electrons to well below tether-foil thickness, while keeping radiation dose still reasonably low. The drag efficiency of a shorter tether could, however, make necessary use of gravity assists to allow orbit insertion. Scientific operation is made easier by the shorter tether, as discussed in the work to be presented.

References

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