Angular momentum actuator network architecture for bending, length change, grapple docking and orbit upkeep of bi-helical space junk mitigation tether

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ABSTRACT

Magnetically contained ball bearings & brushless torquers store Angular Momentum where stiff strands cross in a long bi-helical space tether, reacting against the structure of the smart-guided self-actuating beam w/ grapple to grab and toss down junk (Toss Down or TD Mitigation). The semi rigid structure is able to tailor its own bending forces and physical orientation. This allows optimization of grapple speed and trajectory relative to the center of mass of the extended semi-rigid tether system, for use in relative maneuvering to grapple and deorbit passing junk.

Terminal optical guidance fed from grapple to control process allows system state refresh through flexural and extensional actuation as required to match grapple speed with the targeted junk per control algorithm. The longer the tether, the longer the available time to steer the grapple to the target. Fast approaches require better (finer) structural control, sensory and actuation performance. These basic parametric trades along with combined tether attributes of mass per length and power per length, torquer definition and strand properties provide necessary definition for numeric simulation, tether system performance estimation and design evolution.

Slowly varying cross-section of the strands as well as the tether helix diameter allows an overall ‘muscle fiber’ structural configuration of the system. “Beefy” cross-wound bi-helical strands at the wide portion of the ‘muscle fiber tether’, with co-arranged larger angular momentum actuators afford power and leverage to fling or ‘whip’ the lighter weight grapple end to high speed relative to the system Center of Mass (CM). This is especially true within a region of the tether where the Angular Momentum nodes are up-sized to add mass per unit length and the strands are thicker, stronger and heavier. The system can move more mass or process more momentum if it is more massive itself, which also costs more to launch. Extended system length and a high ‘muscle fiber’ helix max diameter for the principal system work engine permit bending and longitudinal contract-extend actuation, in phase with system rotation across a gravity gradient, to put the tether CM and therefore also the grapple on the target.

A second maneuver is optimized for de-orbit of the junk while adding to the tether’s orbital energy, helping it to its next indicated target. Targets may be chosen in sequence to facilitate minimal orbit transfer of the tether system from one target to the next. The ‘reach’ direction to the current target and the throw direction for junk de-orbit are calculated for net impulse that drives the tether to match target orbits. The system should also have solar power distributed over at least some of its length and ion drive, with fuel tankage that can be transferred to the tether and self-installed by the system as replacements become necessary. A few thrusters could slowly drift the system orbit to the next target while system rotation and grappling phase are calculated and gradually established in the structure.

An additional class of energy conversion maneuvering or “climbing” may be executed using end-over-end rotation of the tether’s length in a plane largely parallel to the orbit plane. An extended section of enlarged helix diameter, heavier tether section and a counterweight at the non-grapple end aid in “inchworm” climb ability. Bending and extension/contraction pull the lower tether section through the rotation faster by contracting the low end of the tether while torqueing at mid-length, then extending the accelerated section as it gets flung to the high side of the rotation. Torqueing and contraction-extension cycles combine to perform work on the center of mass of the tether relative to the orbit, thus adding Specific Mechanical Energy and/or Angular Momentum to the orbit faster than possible with ion drive alone. This is possible using mechanical work of tether shape change through a gravity gradient. This technique and the relative speed requirements for effective mitigation drive the system configuration and fleet size.

A fleet of these tethers could allow the smaller percent to perform grapple & throw-down while the rest transfer between rendezvous orbits. Tethers could also grapple each other and exchange orbital mechanical energy to increase diversity of target opportunities, perhaps working in ‘squadrons’ on specific families of junk orbits.ß