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Friction, mechanical and ageing properties of surface modified materials for space debris capture

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Abstract

Space debris removal is a challenging problem for a clean and safe space environment. The present paper focuses on a novel concept of capture mechanism in the framework of technologies, strategies and concepts known as "tentacles with belts" method.

Within this framework two different strategies (based on inorganic or organic materials) have been developed in order to improve the capture efficiency of the belts.

The mechanical, tribological and ageing characterization of modified belt fabrics for space application is reported and discussed.

Keywords: Space debris removal; Chaser; Belt; Coefficient of friction; Target capture; Adhesive

1. Introduction

The challenge of large space debris removal in Low Earth Orbits, such as spent launcher upper stages or satellites having reached their end of lifetime, is recognized by the most important space players as a necessary step to be overcome in order to make progresses towards a cleaner and safer space environment (Liou et al., 2004; NASA, 2008; Liou, 2014). This is also a mandatory condition for making future space-flight activities safe and feasible in terms of associated risks.

In order to remove such large debris, a so called "non-collaborative rendezvous and capture procedure" to be performed by a robotic spacecraft "chaser" is required.

Different enabling technologies have been identified to accomplish this task, such as:

- techniques for orbital recognition of the target debris, based on images obtained in situ by the chaser spacecraft via optical sensors;
- technologies of autonomous guidance, navigation and control for phases of close rendezvous, final approach and capture;
- technologies, strategies and concepts for target capture and consolidation and locking of achieved link.

Focusing on this last one, a key functionality required by an Active Debris Removal (ADR) mission is the capture of a target object (debris) with a residual spinning motion.

Within the frame of CADET project (Chiesa et al., 2013), a novel concept of capture mechanism, nicknamed

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"tentacles with belts" has been proposed. It looks like a clamping mechanism (also known as a.k.a. "tentacles" in ADR missions literature), obtained by fabric-made belts; the tentacles put a couple of belts around the target body, and then belts are tied around it.

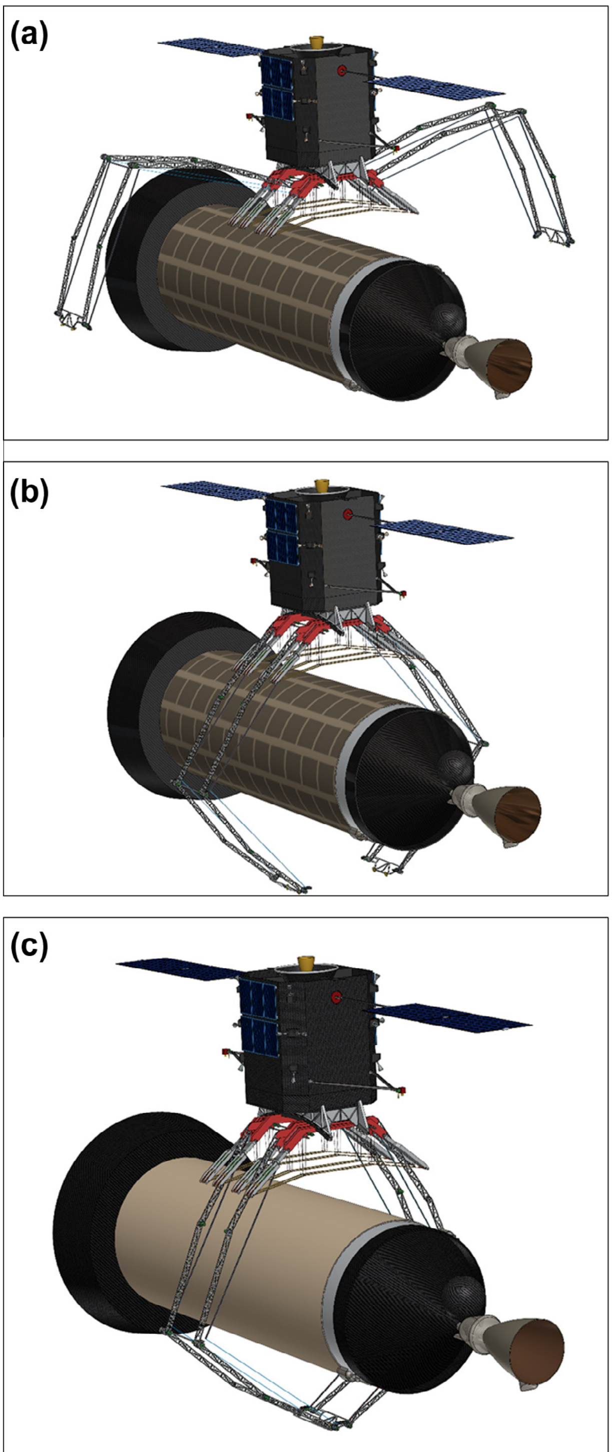

Fig. 1. (a) Step 1 – the chaser approaches the target and deploys its tentacles, (b) Step 2 – the tentacles closes around the target, (c) Step 3 – the tentacles have buckled two belts, which are then tied around the target to create a mechanical link with the chaser (Chiesa et al., 2013).

The concept is shown in Fig. 1(a–c), where the capture sequence on an Ariane 4 upper stage (Ariane H10) is presented.

This novel concept is very innovative with respect to strategies commonly retrieved in literature (e.g. nets, harpoons, robotic manipulators) as:

- It features pros of techniques (such as using a net) based on flexible–rigid contacts (less risky than rigid–rigid contacts);
- It features pros of techniques (e.g. robotic manipulators) with a semi-rigid or rigid configuration of the "stack" (i.e. the ensemble of linked target and chaser) for which the after-capture mission phases (target stabilization and propelled de-orbiting) are much easier than a flexible–link configuration.

Table 1 summarize a qualitative risk assessment for what concerns mechanical risks related to capture and shows the potential advantage of "tentacles with belts" technique.

At this stage, it becomes critical to be able to de-spin the target while not generating stresses on its external structure, which could be potentially hazardous (indeed, one of the key requirements for any ADR mission is not to generate additional fragmentation debris).

After this, the objective is to achieve a mechanical link as stable as possible and able to withstand the loads generated in the after-capture mission phases.

The idea behind this work is a method able to accomplish both functions (target de-spinning and link consolidation) by providing the belts with variable coefficient of friction (CoF), to be modulated according to the characteristics of each mission. Basically, a step-wise increase of the CoF would be mechanically an optimal solution, i.e. starting from a low value (which could be useful to slow the spinning motion of the target without generating high-stresses on its) and increasing to a very high value when the mechanical configuration achieved has to be locked (i.e. generate a very strong adherence between the belts and the target body).

One option to obtain that is adding a layer of adhesive material on the belt surface in contact with the target.

The ideal case would be a controlled activation of the adhesive (for instance, by application of an electrical stimulus), so that the coefficient of friction increases after the de-spinning is completed and the link consolidation can be obtained. However, such solution has some drawbacks in terms of complexity, and the choice of a suitable electrically activated adhesive, if any, has to be found.

The application put some constraints on the adhesives to be selected, as the ability to withstand harsh space environment (very high thermal ranges, vacuum, chemical agents such as monoatomic oxygen) is to be considered at first.

This work describes the experimental activities that have been carried out to change the coefficient of friction of a