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Engineering Notes

Tether System in Martian-Moons-eXploration-Like Mission for Phobos Surface Exploration

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Nomenclature

a	=	abscissa of the L_1 libration point, m
d	=	distance between tether's end mass and Phobos center, m
G	=	Newtonian gravitational constant; $6.67428 \cdot 10^{-11}$, $m^3 \cdot s^{-2} \cdot kg^{-1}$
μ	=	$m_2/(m_1 + m_2)$
m_1	=	mass of Mars, kg
m_2	=	mass of Phobos, kg
m_3	=	mass of the main spacecraft, kg
m_4	=	mass of the tether's end mass, kg
n	=	mean motion, s^{-1}

Subscripts

1	=	Mars
2	=	Phobos
3	=	main spacecraft
4	=	the tether's end mass

I. Introduction

IN THE last half-century, the field of space tether systems has attracted much attention; and this is reflected in several books (e.g., Refs. [1–3]) and in hundreds of papers (e.g., Refs. [4–26]). The book by Beletsky and Levin [1] played a key role in providing the basis for studying the dynamics of the space tether systems. The tether systems are being developed, not only for future missions in near-Earth and lunar space but also as a new technology for exploring the planets of the solar system, their satellites, as well as the asteroids. Currently, the largest of the Martian moons, Phobos, is the subject of intense scientific research regarding its origin as well as its physical and chemical properties, with the aim to further deepen our understanding of the Martian system. In particular, the first attempts are being made to explore the possibility of using tether systems to study Phobos. In 2018, NASA proposed an innovative architecture of a mission called the Phobos L1 Operational Tether Experiment (PHLOTE) to explore the surface of Phobos using a tether system "fixed" at the L1 libration point by means of an orbiting spacecraft [27]. This mission was analyzed in detail, and an alternative tether system anchored on the Phobos surface under the L1 libration point was proposed in the papers of Refs. [28,29]. For the past few years, one of the issues discussed is the Martian Moons eXploration (MMX) mission of the Japan Aerospace Exploration Agency, which is planned to bring back the first samples from Phobos from 2024 to 2029 [30–39]. As part of this mission, a rover (~40 kg) will be delivered to the Phobos surface, and it will explore a small area [40,41]. PHLOTE-like missions provide an opportunity to study only a small area of the surface of Phobos under the L1/L2 libration point. Placing a tether system on periodic orbits about Phobos, such as halo orbits and Lyapunov orbits, does not allow exploration of a large area of the moon's surface because these orbits are located near libration points L1 and L2 [42]. The practical use of these orbits is difficult because they make hazardous close approaches to the surface of Phobos. The Lyapunov and halo orbits are too unstable or come dangerously close to Phobos: some as close as hundreds of meters from the surface of the Martian moon [43]. A Keplerian orbit cannot be used to observe Phobos because the gravity field of Mars dominates the vicinity of Phobos. Even an object on the surface of Phobos still experiences acceleration from Mars's gravity that is two orders of magnitude larger than the gravitational pull of Phobos itself. Phobos's sphere of influence is approximately 7.3 km, which is below its surface [44]. When considering possible options for three-body orbits around Phobos, distant retrograde orbits (DROs), which are also called quasi-satellite orbits (QSOs), stand out as strong candidates [44]. QSOs are of great interest for the exploration of planetary moons because of their dynamical features and relatively close proximity with respect to the surface of Phobos. QSOs of any size are neutrally stable in the circular restricted three-body problem [45]. Although this does not guarantee stability in more accurate dynamical models, it has been shown that QSOs can remain quasi periodic for at least seven days around Phobos [46]. It should be noted that QSOs will be used in the MMX mission. The spacecraft will be placed on quasi-satellite trajectories near Phobos, studying its dynamical and geophysical features for more than three years. The MMX mission will use a rover provided by the Centre National d'Etudes Spatiales and the DLR, German Aerospace Center for scientific and engineering purposes [40]. In addition to performing scientific research, the MMX rover will also serve as a scout, preparing for the landing of the main spacecraft and for the sampling operation, where the whole MMX spacecraft will be landing on Phobos for a few hours. The rover is planned to be released from the main spacecraft at an altitude of less than 100 m before ballistically descending to the Phobos surface. MMX-like missions can be complemented by a sensor package attached to the main spacecraft by a tether. The spacecraft moves in a QSO at a distance of about 10 km from the Phobos surface. The tether is long enough to bring its end mass to a distance of several tens or hundreds of meters to the surface, directly under the QSO, to conduct scientific experiments. The simple and relatively inexpensive tether system would expand the capabilities of MMX-like missions and allow, for example, landing the rover on the Phobos surface at a much lower vertical velocity than in the MMX mission and retracting it to the main spacecraft.

The Note focuses on the development of a new mission to explore Phobos using a tether system deployed toward Phobos from a main spacecraft orbiting in the QSO around Phobos. The objective of the work is to study the possibility of using the tether system deployed from the QSO to study the Phobos surface at a low altitude, as well as to deliver a payload to Phobos. This is the first of its kind to investigate the feasibility of the mission with the tether system deployed in the QSO around Phobos.

The implementation of the purpose is carried out in the Note in four stages:

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