Dynamics and Wave-Based Control of Orbiting Flexible Spacecraft with Propellant-Filled Tanks

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Abstract. The current exponential growth of the space industry makes it imperative to establish a robust and highly performant attitude control method for the coupled dynamics of fuel sloshing and structural vibrations of orbiting spacecrafts. The complexity of the dynamics modelling is avoided by the wave-based control method which is non-model dependent. The present work is to assess the potential of the Wave Based Control (WBC) for floating underactuated flexible systems, specifically for the attitude control of orbiting spacecraft undergoing different coupled nonlinear dynamics such as fuel sloshing dynamics and appendages flexible modes. A general formulation of WBC for non-uniform systems is established. Results of the application of the GFWBC on different flexible fuel-filled spacecrafts are analyzed and an optimized GWBC methodology is proposed.

Introduction

In despite of the appearance of solid and gel propellants and the increasing use of electric ion thrusters for spacecrafts, liquid propellant remains the main source of power for the current missions to the outer space. Furthermore, persistent futuristic projects such as establishing spatial fuel stations, on-orbit refueling and shipment trips to deliver propellants or/and other kinds of liquids to the outer space explain the imperative need for robust attitude control systems to adequately conceal the disturbances produced by the coupling between the different dynamics of the flexible structures, the spacecraft attitude and the fuel sloshing. The time between the earliest incident caused by fuel sloshing, of Jupiter Intermediate Range Ballistic Missile in 1957, and the latest, of Falcon-1 in 2007, is 50 years, this long period reflects the complexity of the modelling and control of such flexible systems with coupled and unpredictable dynamics like those caused by the fuel slosh.

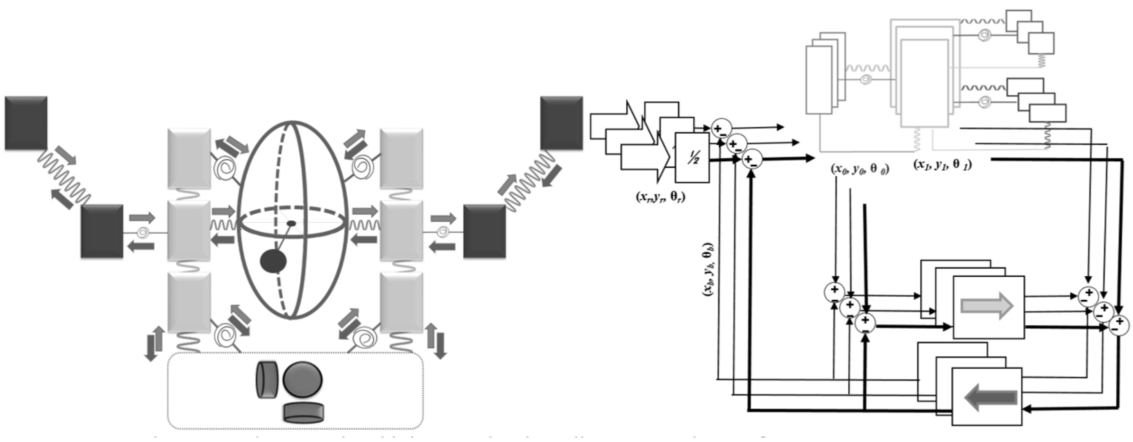

Figure 1: Example of the Launched and Absorbed Mechanical Waves in a Spacecraft Model and WBC Diagram.

Contrarily to WBC, active control methods to date depend strongly on an accurate modelling of the fuel slosh dynamics and a precise description of the coupling between the different motions on the orbiting spacecraft, which are have yet to be found. The WBC method has been inspired from the concept of wave absorption in flexible lumped systems, similarly, the motion in a flexible spacecraft travels through its components till the tip, some of it reflects and return and another part gets absorbed or leaves. This method particularity is that it deals with the coupled disturbances as a whole, in the form of traveling waves, instead of controlling each source of each motion separately. The controller is designed to absorb all the returning waves just at the level of the actuator interface no matter how large or chaotic they are. However, to date the wave-based modelling and control of only modest uniform aerospace systems have been considered and many notions remain ambiguous. In this work the current WBC is extended to non-uniform systems and a general formulation has been built. Where, masses and springs stiffness throughout the system have different values, wave-based transfer functions with higher order are derived, and more partial internal reflections of waves are witnessed as they propagate through the system. The application of the GWBC on non-uniform liquid-filled spacecraft models proved more adaptability to real aerospace problems and better highlighting of the WBC efficiency.

References

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