Comparison of LQR, LQG and H-infinity Methods to Design Controllers for a Satellite considering Fluid-Structure Interaction

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Abstract

The Fluid-Structure Interaction (FSI) problem occurs when the dynamics of some movable or deformable structure interacts with the dynamics of any internal fluid. This is the case of a rigid-flexible spacecraft with fuel tank inside it. In the Attitude Control System (ACS) design for this type of spacecraft, a crucial interaction can occur between the rigid motion, the fuel slosh motion and the flexible panels' motion during translational and/or rotational manoeuvre. Those interactions can change the spacecraft center of mass position damaging the ACS pointing accuracy. In this paper one develops a mathematical model for a rigid-flexible satellite considering the fuel slosh dynamics which is modelled using a common pendulum model which is considered to be unactuated. That model is used to design and compare the satellite ACS by the Linear Quadratic Regulator (LQR), the Linear Quadratic Gaussian (LQG) and the H-infinity methods in order to discuss the advantages, disadvantages and limitations of each method. The control inputs are defined by a transverse body fixed force and a moment about the centre of mass. A comparative investigation of the LQR and LQG methods has shown a significant improvement in the satellite ACS performance of what has been done previously, since it is possible to control, simultaneously, the rigid-flexible motion and the fuel slosh motion. On the other hand, although, the H-infinity controller design is preliminary, it has the advantage of including the uncertainties of the system in the design process, resulting in more robust controller.

Keywords: Rigid-flexible Satellite, Fluid-Structure Interaction, Robust Control System

Introduction

The problems due to Fluid-Structure Interaction (FSI) are crucial in the design of many engineering system. They appear in the dynamic behavior of offshore and marine structures, road and railroad containers partially filled with a fluid [1]. In space applications the problem appears when the dynamics of a rigid satellite with liquid fuel inside interacts with flexible structures [2]. One notes these problems are more relevant when the slosh unactuated dynamics motion has to be simultaneously controlled together to the rigid-flexible motion of the satellite [3]. In the Rigid-flexible satellite Attitude Control System (ACS) design the knowledge of the interaction between fluid motion (slosh) and flexible structure dynamics is important because this interaction can damage the ACS pointing requirements. A space structure, like rockets, geosynchronous satellites and the space station usually contains liquid in tanks that can represent more than 40% of the initial mass of the system. As a result, the first step to design its ACS is to obtain a detailed dynamics model of the space structure. When the fuel tanks are only partially filled and suffer a transversal acceleration and/or rotational motion, large quantities of fuel moves uncontrollably inside the tanks and generate the sloshing effects. It has been shown in [4] that the dynamics interaction between the fuel motion and the rigid and/or flexible body dynamics can result in some kind of control instability. For minimizing these effects the ACS must be designed using a robust control method in order to assure stability and good performance to achieve the attitude control system requirement [5]. The dynamics of rigid-flexible satellite with fuel tanks when subject to large angle manoeuvre is only captured by complex non-linear mathematical model. Besides, the remaining flexible and/or liquid vibration can introduce a tracking error resulting in a minimum attitude acquisition time. The problem of designing satellite nonlinear controller for rigid satellite has been done in [6] using the State Dependent Riccati Equation (SDRE) method which is able to deal with high nonlinear plants. Due to the complexity of modelling the fluid and/or flexible dynamic of the system it is common to use mechanical systems analogies that describe this dynamic. Besides, if one needs to know some physical parameters related with the slosh or the flexibility dynamics it is common to obtain then by experimental apparatus or some kind of estimating method such as Kalman filter [7]. In [8] a new technique to control the attitude of a rigid-flexible satellite has been developed where a reaction wheel was used for controlling the angular motion and the vibrations are damped by piezoelectric patches that are symmetrically bonded in the panel's surfaces. A multi-objective approach has been used in [9] to solve the problem of optimal flexible solar sail trajectories control. A similar investigation has been done in [10] where besides the design of the controller considering the effects of the interaction between the liquid motion (slosh) and the rigid dynamics, the parameters of the fuel slosh dynamics modelled by a simple pendulum are identified using the Kalman filter technique. The H-infinity Control Method has been applied in [11] to design an Attitude Control System of a rigid-flexible satellite.

References

[1] Chakrabarti, S. K. Internal waves in a large offshore storage tank. Journal of Energy Resources Technology, 115:134-141, 1993.

[2] Hill, D. E. and Baumgarten, J. R. Control of spin-stabilized spacecraft with sloshing fluid stores. Journal of Dynamic Systems, Measurement, and Control, 114:728-731, 1992.

[3] Lui A. P. and Lou J. Y. K. Dynamic coupling of a liquid-tank system under transient excitations. Ocean Engineering, 17(3):263-277, 1990.

[4] Agrawal, B. N. Dynamic characteristics of liquid motion in partially filled tanks of a spinning spacecraft. Journal of Guidance, Control and Dynamics, 16(4):636-640, 1993.

[5] Sidi, M.J., 1997, Spacecraft dynamics and control, Cambridge university press, New York.

[6] Souza, L. C. G. ; Gonzales, R. G. Application of the State-Dependent Riccati Equation and Kalman Filter techniques to the design of a satellite control system. Shock and Vibration, v. 19, p. 22-28, 2012.

[7] Souza, L. C. G. Design of Satellite Control System using Optimal Non-Linear Theory, Mechanics Based Design of Structures and Machine, (1), 2008, pp. 1-20.

[8] Sales, T. P. ; Rade, D. A. ; Souza**,** L.C.G. Passive vibration control of flexible spacecraft using shunted piezoelectric transducers. Aerospace Science and Technology, v.1, (2013), p. 12-26.

[9] Mainenti I. L; Souza, L. C. G. Souza, F. L. Design of a nonlinear controller for a rigid-flexible satellite using multi-objective Generalized Extremal Optimization with real codification. Shock and Vibration, v.19, p. 1-10, 2012.

[10] Souza, L.C.G ; Souza, A. G. . Satellite Attitude Control System Design considering the Fuel Slosh Dynamics. Shock and Vibration, v. 2014, p. 1-8, 2014.

[11] Cubillos, X C M and Souza, L C G. "Using H-infinity Control Method to Design an Attitude Control System of Rigid-Flexible Satellite". *Mathematical Problem Engineering.* (1),2009, pp. 1-10.