Paper ID: 9750
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ASTRODYNAMICS SYMPOSIUM (C1)
Attitude Dynamics - Part 2 (6)

Author: Dr. Seon-Ho Lee
Korea Aerospace Research Institute (KARI), Korea, Republic of

COMMAND SHAPING FOR NONLINEARITY COMPENSATION OF REACTION WHEELS IN SPACECRAFTS

Abstract

This paper presents a command shaping method applicable to the nonlinearity compensation of reaction wheels widely used in spacecrafts. It is well known that the reaction wheel that is the main actuator for the momentum storage and exchange generates the physical torque for the attitude maneuver and stabilization of spacecraft. More specifically, the reaction wheel has a nonlinearity of the bearing friction discontinuity at zero-crossing of wheel speed due to the inherent mechanism of its bearing system. Generally, the friction discontinuity generates an undesirable impulsive jerk disturbance that causes an abrupt increase of control error in attitude control system of spacecrafts and as a consequence it gives an impact to the image quality and geo-location characteristics during the imaging taking mission of spacecrafts. Thus, in order to prevent the control performance degradation due to the nonlinearity, this paper proposes two types of feed-forward compensators for shaping the torque command to reaction wheel such as the sinusoidal-based and the parabola-based compensators depending on the basis function used for the shaping. The sinusoidal-based compensator formulated with the known friction model reduces the jerk disturbance to the pre-defined level by adjusting the shaping region of wheel speed more effectively than the parabola-based compensator. However, since it should solve nonlinear equations to find the design parameter of the compensator, there exists a limitation of on-board implementation in practice. On the other hand, the parabola-based compensator formulated with an estimated friction model solves the linear equations whose solution is obtained in a closed form and thus it is applicable to the real-time computation. Particularly, the friction parameters is estimated by the least square algorithm during the transient motion of spacecraft maneuvering by accelerating and decelerating the wheel speed. Then the estimated parameters are applied to the compensator at the steady-state where the wheel speed is stabilized around zero. This paper analyzes the shaping torques, the compensated torques, and the amount of jerk reduction depending on the various shaping regions of wheel speed for both compensators. The usefulness of the proposed method is evaluated with a simulation of attitude control systems composed of a proportional-derivative controller, a reaction wheel with an uncertain friction model, and a spacecraft dynamics. The simulation demonstrates that an increase of the steady-state attitude error and an unwanted chattering phenomena in the reaction wheel generated torque is eliminated with an implementation of the parabola-based compensator.