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Active control for initial attitude acquisition using magnetic torquers

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Abstract

This paper presents an active control design for spacecraft initial attitude acquisition (IAA) by using two magnetic torquers on the X and Y body axes. A very robust and fully autonomous design for IAA can be fulfilled by the use of a simple magnetic control law, a proportional-plus-derivative controller. A modified "B-dot law" provides the derivative control action while the cross product of spacecraft $+Z$ body axis vector and geomagnetic field vector provides the proportional control action. Attitude motion of the spacecraft is reduced by forcing the spacecraft's $+Z$ body axis to align with the Earth's magnetic field vector. Simulation results are provided to demonstrate the design. When the initial deviation is not large, the attitude convergence can be completed in one orbit.

1. Introduction

The attitude control system (ACS) of a spacecraft is to provide stable attitude control and knowledge throughout all phases of flight, from post-launch separation to deorbit maneuvers at the end of life. Specifically, for a low-Earth-orbit (LEO) nadir-pointing spacecraft, the ACS must have the following functions:

- to provide attitude knowledge during normal operations and orbit transfer,
- to hold a nadir-pointing orientation during normal operations (zero pitch, roll, and yaw angles),
- to transit the satellite from post-launch separation to a stable, nadir-pointing orientation, and
- to recover the spacecraft from a tumbling status to a safe orientation autonomously.

A spacecraft could be tumbling after separation from the launch vehicle. Obviously, the controller design for the initial attitude acquisition (IAA) is a challenging

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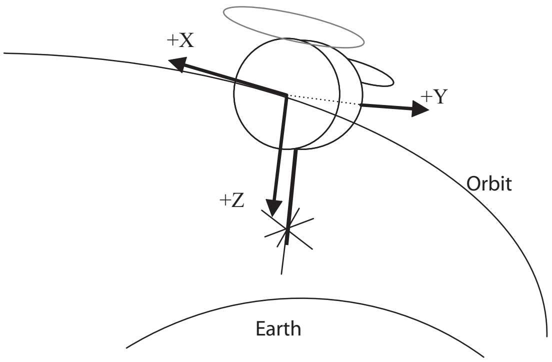

Fig. 1. Spacecraft body coordinates.

task. The difficulty is that there is usually no attitude information at this stage. In other words, the control scheme must be able to bring the spacecraft to a safe and deterministic orientation without prior attitude information. It is quite often to use the magnetic control for initial attitude acquisition owing to well understanding of the Earth's magnetic field. Moreover, since the magnetic control system is reliable, lightweight, and energy efficient, it is usually considered for small, inexpensive satellites.

In many applications, the use of magnetic torquers is mainly for the attitude acquisition control of spin stabilized satellites with spin axis inertially fixed [1,2]. These kinds of controller are mostly used for nutation damping or slewing of the spin axis. To align a specific spacecraft axis along the geomagnetic field is another attractive control object. This control object can be achieved through the use of permanent magnets with hysteresis rods [3]. Basically, this is a method of passive magnetic stabilization. To align a specific spacecraft axis with the geomagnetic field using active magnetic torquers was not often discussed in the open literature.

In this paper, an active control methodology is developed to perform IAA with two magnetic torquers. The control system for the IAA can reduce the angular rate and align the spacecraft $+Z$ body axis with the Earth's magnetic field vector. Near the Northern most point, the spacecraft attitude will be closely nadir pointing when the spacecraft's $+Z$ body axis tracks along with the magnetic field. Figs. 1 and 2 show the spacecraft body coordinates and the spacecraft attitude in IAA, respectively.

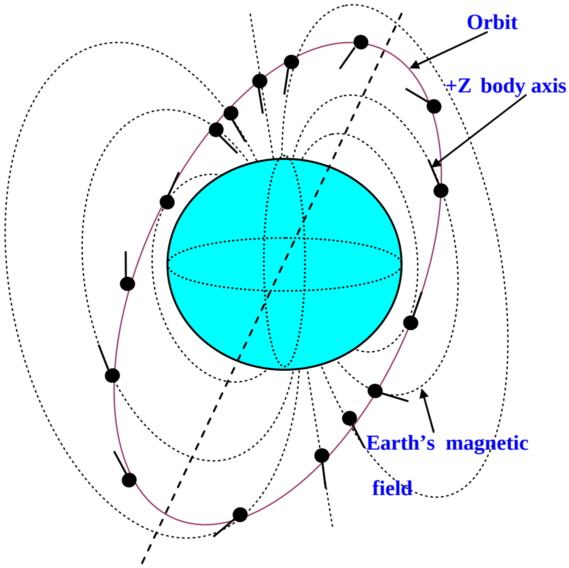

Fig. 2. Spacecraft attitude in initial attitude acquisition.

2. Magnetorquing

Two torquers aligned with X- and Y-axes will be used primarily for attitude control in the IAA. The vector dipole moment $\vec{M}$ of magnetic torquer rod will interact with the geomagnetic field vector $\vec{B}$ to generate a magnetic torque $\vec{N}$,

$$\vec{N} = \vec{M} \times \vec{B}, \tag{1}$$

where $\vec{M}$ is determined by on-board controller and geomagnetic field vector $\vec{B}$ is measured through the on-board magnetometer.

3. IAA controller design

The objective of IAA controller is to reduce the angular rate of spacecraft and to align its $+Z$-axis with the Earth's magnetic field. To accomplish this,