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Design and test of a 300Wh composites flywheel energy storage prototype with active magnetic bearings

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Abstract. A flywheel energy storage prototype was designed and built to get high energy density and low bearing loss. The aluminium alloy hub formed by thin plate and shell connected the bearing shaft and the rim which was composed by glass fibre and carbon fibre reinforced composite. Finite element analysis on stress field of the composite flywheel indicated that the flywheel could run at the rated speed of 700 r/s (rotation per second) safely. The flywheel was supported by 5-degrees of freedom active magnetic bearings (AMBs). The flexible modes of the rim-hub-shaft system were analyzed by using finite element (FE) based software. The complex non-synchronous vibration was observed, analyzed and suppressed during testing of the flywheel system.
The control method of adding phase compensator to the velocity channel in the cross feedback controller was presented to make the supporting AMBs work better while the flywheel passed through its first flexible mode. The field balancing at high speeds enabled the flywheel to reach the speed of 475 r/s with small amplitude of synchronous response.

Key words

Flywheel energy storage; Composites; Active magnetic bearings

1. Introduction

Application of high speed flywheels as mechanical batteries to store energy becomes increasingly attractive in recent years [1]. In opposition to chemical batteries, the life of AMB flywheels has no degradation during the entire design life. A spinning flywheel has capability to accumulate a large amount of kinetic energy. Therefore, having an integrated motor/generator, the well controlled flywheel can be used not only for the attitude control but also for energy storage in spacecraft [2,3].

One of the main sources of energy loss in flywheels is attributed to bearings. With the introduction of frictionless active magnetic bearings, the efficiency of flywheels for energy storage has been increased to an economically useful level. Electrical active magnetic bearings (AMBs) satisfy the frictionless condition but require advanced control systems [4, 5]. Although the super-conducting bearings have been developed to replace conventional bearings [6, 7], they require cryogenic conditions, and AMBs still remain the best bearing alternative for flywheels in spacecraft application.

To demonstrate the possible space application of the advanced composite flywheel with AMBs, the experimental high speed (in rated rotational frequency of 700Hz) FES-AMB system was designed and built in Tsinghua University. The stress and stain field of the flywheel was solved by FEM, which indicated that the structural failure would not happen while the rotational speed being up to 700 r/s. It was found difficult to use the conventional cross feed back control to make the flywheel stable when it passes through the resonant vibration district because of the flexible mode due to the flexible hub connection between the shaft and the rim. Compared with the past literature, the new challenge is the coupling between the strong gyroscopic and the flexible mode resonance at the high speed around 400 r/s.

The complex nonsynchronic vibration behaviour was observed and analyzed during experimental testing of the flywheel system with flexible components. Several control methods were successfully applied to suppress the unexpected modal vibrations. The AMB controller was revised and substantially improved to guarantee stable operation when the flywheel passed two rigid modes and the first flexible mode.