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Instantaneous Torque Control of Magnetically Suspended Reaction Flywheel

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Abstract

With the requirement of spacecraft attitude control accuracy, the reaction flywheel is demanded deliver higher precision torque. To improve the torque-output precision of the magnetically suspended reaction flywheel, a new torque control method is proposed. First, comprehensive analysis of torque ripple of brushless DC motor (BLDC) due to commutation and inactive phase diode freewheeling is presented. Second, in order to eliminate the diode freewheeling of the inactive phase, the modulation PWM_ON_PWM pattern is adopted. Third, compensation methods to attenuate the commutation torque ripple by modulating the switching-in phase during low-speed region and modulating switching-out phase during high-speed region are given. Upon this, calculation method of the commutation time is introduced. Finally, the experimental results show that the proposed methods can eliminate both commutation and non-commutation torque ripple efficiently.

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Keywords: brushless dc motor (BLDCM), commutation, diode freewheeling, torque ripple;

1. Introduction

The reaction flywheel is the key actuators for spacecraft attitude control [1]. The main task of reaction flywheel is to carry out the torque command which given by the spacecraft attitude control system to provide reaction torque for spacecraft. With the requirement of spacecraft attitude control accuracy is higher and higher, the reaction flywheel is demanded to deliver higher precision torque. A magnetically suspended reaction flywheel (MSRW) has the character of long-life, low-vibration and high-precision owing to its zero friction and enhanced damping of rotor,

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and will be the first choice of the new generation spacecraft plats with high-stability and high-precision. The output torque accuracy of magnetically suspended reaction flywheel is affected mainly by the torque accuracy of flywheel drive motor. Torque ripple reduction is a difficult point for achieving high-precision electromagnetic torque. As far as motor selection is concerned, brushless dc motors with ironless and slotless stator are superior in space application reaction flywheel owing to its simple control, high power density and low cost.

Torque ripple results in vibration speed ripple and unwanted acoustic noise. In order to improve the performance of BLDCM in the high-precision filed, torque ripple reduction of BLDCM has always been the hotspot and difficult point in recent years. The studies mainly focus on commutation torque ripple and torque ripple caused by diode freewheeling of inactive phase. In classical literature [2], the reasons of commutation torque ripple are first analyzed, but the approach to eliminate commutation torque ripple is not given. In [3], a novel circuit topology and a dc link voltage control strategy are presented, the commutation torque ripple is minimized efficiently. This method adds complex circuits into system, hence the reliability of the system is decreased. In [4], in order to equal the average current slew of switching-out phase with the switching-in phase, a method by divide each pulse width modulation (PWM) period into three segments during commutation interval to decrease the commutation torque ripple and regulate commutation time. In [5], the influences of different PWM modes on commutation torque ripple are given to select a better one to decrease it. All the methods mentioned above perform to reduce commutation torque ripple, and no non-commutation torque ripple is related.

For the diode freewheeling of inactive phase during non-commutation, the PWM_ON_PWM methods are considered[6]-[8]. This method works and can attenuate the inactive phase diode freewheeling. But no studies consider commutation and non-commutation torque ripple simultaneously.

This paper proposes methods to attenuate the commutation torque ripple and non-commutation torque fluctuation for the MSRW BLDCM. In this paper, the modulation PWM_ON_PWM pattern is adopted to eliminate the diode freewheeling of the inactive phase. Methods of modulating the switching-in phase during low-speed region and modulating switching-out phase during high-speed region are given. In addition, calculation method of the commutation time is introduced. The experimental results show that the proposed methods can eliminate both commutation and non-commutation torque ripple efficiently.

2. Modeling for The BLDCM of MSRW

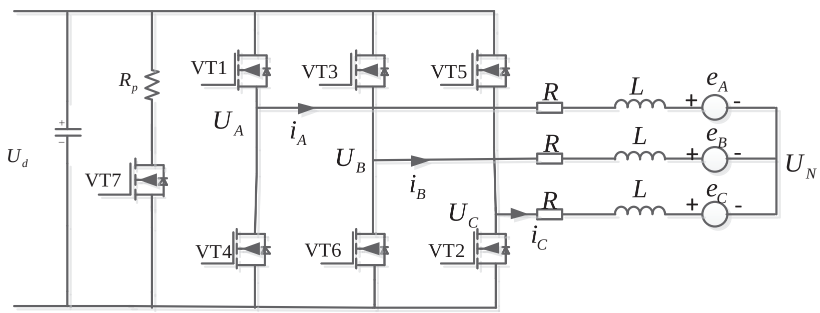

Fig. 1 The drive circuit configuration of BLDCM

As shown in Fig.1, the drive circuit configuration of MSRW motor is three-phase full bridge inverter. The BLDCM three phase are connected in star type. Assume that the three-phase stator winding are symmetrical, the parameter of each is equal and constant, and the inductive electromotive force (EMF) is the trapezoidal waveform. The voltage equation of BLDCM three windings with phase variables is