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Magnetic levitation of a one DOF system using simultaneous actuation and displacement sensing technique

Tau Meng Lim *, Shanbao Cheng

Division of Mechatronics & Design, School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

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ABSTRACT

This paper discusses the development of a displacement self-sensing estimator for a one degree of freedom (DOF) magnetically levitated system using the parameter estimation technique. Current demodulation technique is known to be capable of extracting the air gap length from the coil current with demodulation filters. However, one of its main disadvantages is that its output is a function of the air gap length and the duty cycle of the PWM amplifiers. It is therefore demonstrated here, through computer simulation and experimental investigation, that the self-sensing parameter estimation technique is capable of removing the variable duty cycle from the estimated output. It is composed of two identical demodulation filters, one coil inductance simulator and one PI convergence controller. Benefiting from the closed loop characteristics of the self-sensing parameter estimation, not only is the influence of the duty cycle removed, but the dynamic characteristics of the selfsensing system are also greatly enhanced. The design of the analogue circuitries implementing the algorithm of the self-sensing parameter estimator is described. Very good agreement in the static and dynamic calibrations of the estimator output is observed, when compared with a dial gauge and commercial eddy current probe. While the self-sensing active magnetic bearing (AMB) system is levitated, excellent signal tracking capability of the parameter estimator is noted.

1. Introduction

A typical active magnetic bearing system typically consists of an actuator, a displacement sensor, a controller and an amplifier, and its block diagram is shown in Fig. 1.

However, in some cases, there is a need to eliminate the application of the displacement sensor in the AMB system because the number of wires across the actuator needs to be minimised. The artificial heart pump is a typical example where elimination of displacement sensors is very desirable, because it can reduce the number of wires across the chest to the minimum [1,2]. The elimination of displacement sensors can also improve system reliability because previously, if one displacement sensor failed, the entire bearings system would fail as well, resulting in costly consequences. Furthermore, a rotor-bearing system can be designed to be shorter and stiffer without a discrete displacement sensor. In addition, the problem of sensor/actuator non-collocation, which may cause system instability, can be resolved. Lastly, if the method of self-sensing parameter estimation is used, the need for noise filtering circuits is eliminated because the Pulse Width Modulation (PWM) switching signal is used as information on displacement rather than as noise.

Self-sensing magnetic bearings extract rotor displacement information from the electromagnetic signals of coils. This is because the coil current signal contains the coil inductance information at the switching frequency, and the coil inductance is inversely proportional to the air gap distance [3,4]. Consequently, the high-frequency component of the coil current amplitude contains the rotor displacement information. Demodulation filters are used to extract the displacement information from the coil currents, and this method is known as current demodulation or switching noise demodulation.

A number of researchers [5–11] have successfully employed the current demodulation method with the demodulation filter to obtain the air gap length information. However, due to the PWM amplifiers they have used, their estimated outputs are actually a function of both air gap length and the duty cycle of PWM switching amplifier in their approaches. In [7], linear amplifiers are used to drive the magnetic bearings, but the efficiency of the linear amplifier can be very low due to high I^2R losses [12]. In order to remove the duty cycle from the estimated output, the method of parameter estimation has been proposed by Noh and Maslen [13] to greatly reduce the influence of PWM amplifier's duty cycle, and at the same time improve the system measuring bandwidth.

* Corresponding author.
E-mail address: limtaumeng@gmail.com (T.M. Lim).

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