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Iterative learning control of permanent magnet linear motor with relay automatic tuning

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Abstract

In this paper, a feedforward–feedback control structure is proposed for precision motion control of a permanent magnet linear motor (PMLM) for applications which are inherently repetitive in terms of the motion trajectories. The control scheme utilises an efficient marriage of conventional PID feedback control and an intelligent feedforward control using an iterative learning control (ILC) algorithm. The PID feedback control stabilizes the PMLM system, while the ILC feedforward control enhances the trajectories tracking performance by capitalising on the experience gained from the repeated execution of the same operations. A relay automatic tuning method is developed and incorporated, so that an initial set of control settings may be automatically derived from a few cycles of self-induced controlled oscillations. This self-tuning feature enables the PMLM application system to be operated quickly near optimal conditions simply at a push-button efficiency. Extensive experimental results are presented to demonstrate the appeal and effectiveness of the proposed scheme. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Permanent magnet linear motor; PID control; Iterative learning control; Relay auto-tuning

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1. Introduction

Permanent magnet linear motors (PMLM) are beginning to find widespread industrial applications, particularly in those requiring a high precision in positioning resolution such as stages for various key semiconductor fabrication and inspection processes as in step and repeat micro-lithography, wafer dicing, probing and scanning probe microscopy (SPM). The main benefits of a PMLM are the high force density achievable, low thermal losses and probably most importantly, the high positioning precision and accuracy associated with the mechanical simplicity of such systems. Unlike rotary machines, linear motors require no indirect coupling mechanisms as in gear boxes, chains, and screw coupling. This greatly reduces the effects of contact-types of nonlinearities and disturbances such as backlash and frictional forces [5].

The more predominant nonlinear effects underlying a linear motor system are the various friction components (Coulomb, viscous and stiction) and force ripples (detent and reluctance forces) arising from imperfections in the underlying components [12]. PID controllers, typically used in the process industry, found their successful applications in industrial robots with quite accurate robotics modelling. In PMLM motion systems, it is hard to get an accurate model for the nonlinear effects, specifically like the cogging effect during linear motion [12]. Therefore, due to the ultra-precision positioning requirements and the low offset tolerance of their applications, the control of these systems is particularly challenging since in these application domains a conventional PID controller alone do not usually suffice. Some efforts have been made towards more advanced control of PMLM motion systems. In Otten et al. [12] a neural-network (NN) based feedforward assisted PID controller was proposed. A hybrid control strategy using a variable structure control (VSC) is suggested for submicron positioning control [7]. In these cases and more, the control framework can be described under a feedback–feedforward configuration.

In this paper, we are mainly concerned with the applications of the PMLM in areas involving repeated iterations of motion trajectories, such as pick and place assembly operations and many step and repeat positioning systems. In these typical tasks of PMLM, the time duration for the execution of an operational cycle is finite and finite-time tracking control is always difficult with conventional controllers like the PID controllers which are more suitable for set-point regulation. To achieve a better tracking performance, a feedforward controller is usually applied. In this paper, a new feedforward controller — ILC is proposed and developed as a learning enhancement to a PID feedback controller. The main objective of this feedforward term is to reject exogenous disturbances, and to compensate for the nonlinearities mentioned above which would otherwise limit the accuracy achievable with simple feedback control systems. ILC [2], exploits the repetitive nature of the tasks as experience gained to compensate for the poor or incomplete knowledge of the plant model and the disturbances present. A recent comprehensive survey of ILC can be found in Moore [11] and Xu and Bien [16]. ILC is essentially a memory-based scheme which needs to store the tracking errors