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Robotics and Computer-Integrated Manufacturing 24 (2008) 384–391
Robotics and Computer-Integrated Manufacturing
www.elsevier.com/locate/rcim

Iterative learning variable structure controller for high-speed and high-precision point-to-point motion

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Received 25 January 2006; received in revised form 13 November 2006; accepted 8 February 2007

Abstract

In this paper, an iterative learning variable structure controller is proposed for the fast point-to-point motion. The motion is first divided into two stages: high-speed motion and high-precision positioning. Then the controllers are designed for these two stages, respectively. An iterative learning law is developed to determine the switch position. Based on this switch position a controller is proposed for the high-speed motion. Subsequently, a sliding controller is designed for the high-precision positioning stage. This controller is implemented on an X–Y positioning table. The results of the experiments show that it performs well and almost no overshoot exists if the discontinuous projection is used. The settling time is also reduced greatly, which is very important in the point-to-point motion in this paper.

Keywords: Point-to-point motion; Sliding controller; Linear motors; Iterative learning controller; Variable structure

1. Introduction

Permanent magnet linear motors (PMLMs) are widely used in many fields [1], particularly in those requiring high speed and high precision in positioning resolution such as wire bonding. The main benefits of a PMLM are the high force density achievable, low thermal losses, the high-positioning precision and mechanical simplicity of such systems.

Significant effort has been devoted to controlling linear motors. The authors in [2] give some useful control framework for high performance based on the fact that in motion control, two major sources of uncertainties are friction and inertia. In order to eliminate the effect of the friction, Garagic and Srinivasan [3] proposes a controller to adaptively compensate the friction for precision machines. In fact, without the mechanical transmission mechanisms, the systems driven by linear motors are more sensitive to external disturbances compared to the traditional ones by rotary motors. Thus, it is more difficult to control the linear motors as desired. To deal with the disturbance, the authors in [4] propose a feedforward design for high-speed direct-drive positioning table based on the disturbance observer. In [5], a robust adaptive controller is given to deal with friction and force ripple. Combining the adaptive control and the deterministic robust control, the authors in [6,7] give an adaptive robust controller for high performance by introducing a projection to assure the boundedness of the estimates of the model parameters. Based on a relatively accurate model of high order, an H_∞-based robust and precision motion controller is proposed in [8]. In [9], the authors give a variable structure controller to suppress the overshoot for precise positioning.

For repetitive motions, iterative learning control is the preferred approach and much work has been done. In [10], the authors propose linear iterative learning control algorithm and the necessary and sufficient condition for convergence of the algorithm is given in [11]. It is used in [12] to control linear motors based on the model induced by relay tuning. Also, the authors in [13] use an iterative learning control with a neural network to adjust the reference, instead of adjusting the control signal, for high-precision and repetitive tracking motion.

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doi:10.1016/j.rcim.2007.02.021

In many practices, the system is required to move from one point to another and settle there as fast as possible, i.e., it is a point-to-point motion. To realize the point-to-point motion, it is common that a motion profile is generated first and then the controller makes the system track this profile. So the performance of the system depends on both the motion profile generator and the controller. The widely used motion profile is of third order. In order to reduce the vibration caused by the poorly damped poles of the systems, many methods have been developed such as Impulse Input Shaping. To achieve zero vibration after the movement is complete, the authors in [14] propose an optimal discrete time point-to-point motion profile.

In this paper, an iterative learning variable structure controller is proposed for fast point-to-point motion without demanding the motion profile and implemented on an X–Y positioning table. This control strategy divides the motion into two stages: the high-speed motion and the high-precision positioning. In the first stage, the control signal is set to the positive maximum to make full use of the potential ability to accelerate the system and is switched to the opposite maximum to decelerate the table at some position, i.e., the switch position. If the model is accurate enough, the switch position can be determined properly. But it is time consuming or impossible to get an accurate model. From the fact that the point-to-point motion is repetitive, the switch position can be adjusted iteratively according to the last results. When the velocity reduces to zero, the motion goes into the second stage. It is well known that the sliding controller is suitable to regulate the system [15,16]. So in this stage, a modified sliding controller is used for precise positioning.

As in [9], in different stages, different models of the system are used. A rough model is enough for the high-speed stage while the high-precise positioning stage needs a more accurate one. Although the two models are different, they are related to some extend and appropriate for different stages, which will be synthesized later.

The structure of this paper is as follows. Section 2 gives the models of the system. The iterative learning variable structure controller will be designed in Section 3. The implementation of this controller is given in Section 4, which is followed by the conclusion in Section 5.

2. Model description

Fig. 1 shows the X–Y table positioning mechanism, which is an original platform in many industrial fields such as wire bonding machines. It has two axes, i.e., X and Y, with the Y-axis mounted on top of the X-axis. Each axis is driven by a linear motor manufactured by Kollmorgen and equipped with a noncontact linear optical encoder by Heidenhain. Table 1 shows the parameters of the X–Y table and the parameters of the linear optical encoder are in Table 2.

This platform is required to move from one point to another and settle there as fast as possible, i.e., the motion is of point-to-point. This motion can be divided into two stages: the high-speed motion and the high-precision positioning. As in [9], different models are used in the two stages.

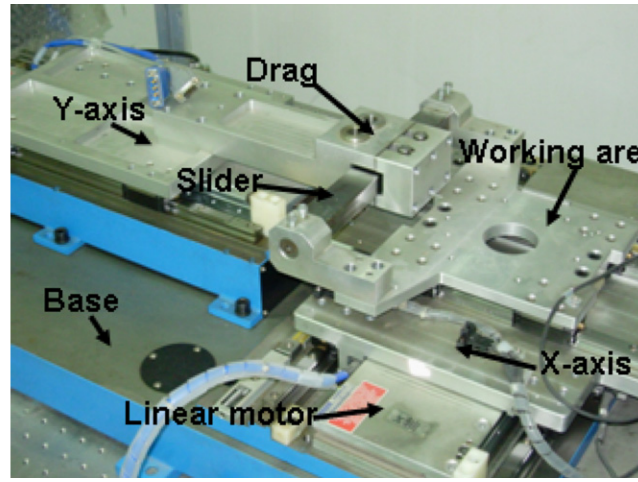

Fig. 1. The X–Y table positioning mechanism.

Table 1
Parameters of the motion table

	X-axis	Y-axis
Total mass (kg)	7.9	10.0
Motor type	IL18-100A1P1	IL18-075A1P1
Peak force (N)	1200	900
Continuous force (N)	270	202
Motor constant ($N/\sqrt{W}$)	17.7	14.9

Table 2
The parameters of the linear optical encoder

Model	Heidenhain LIDA 475
Precision	$\pm 0.5\,\mu m$
Measurement length	$>3000\,mm$
Max tracking velocity	4 m/s
Tracking acceleration	>5 gs

In the high-speed motion stage, a rough model is enough for designing the controller to be proposed in this paper. The nominal model in this stage can be expressed as

$$m\ddot{x} = Ki + F, \tag{1}$$

where m is the mass of the motion part, K is the torque constant, i is the current of the rotor of the motor and F, including the friction force, is the external disturbance with dissipated property. In the second stage, a more accurate model is needed for designing the system to achieve high-precise positioning. However, too accurate model costs much and is not necessary. Thus an appropriate model in this stage can be chosen as

$$m\ddot{x} + B\dot{x} = Ki + F_{\mathrm{d}}, \tag{2}$$