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Design and control of a rotary dual-stage actuator positioning system

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ABSTRACT

This paper presents the design and control of a rotary dual-stage actuator (DSA) positioning system, which has a flexure-based beam driven by a voice coil motor (VCM) and a piezoelectric (PZT) actuator simultaneously. The design goal is to enable the two actuators complementary to each other for the combined ability of high positioning accuracy and a large tangential displacement range. To achieve a high tracking speed, the flexure beam is designed via finite element method (FEM) analysis to have sufficiently high open-loop bandwidth. System identification and measurements on the DSA prototype are also presented to verify the FEM analysis. Finally, the composite nonlinear control (CNC) method is applied to the DSA system. Experimental results demonstrate that the DSA servo system significantly outperforms the single-stage servo system in both step tracking and disturbance rejection.

1. Introduction

A dual-stage actuator (DSA) is typically comprised of two actuators connected in series. The primary (coarse) actuator is characterized by a large travel range but poor accuracy and slow response time. The secondary (fine) actuator is of higher precision and faster response, but with a limited travel range. By combining both actuators with an appropriate control strategy, the limitations of one actuator can be compensated by the merits of the other. As a result, an integrated performance of both high precision and large travel range can be achieved.

The DSA systems have been extensively applied in industry. For example, the dual-stage hard disk drives (HDDs) have been proposed as a possible way to provide a wider servo bandwidth to achieve faster seeking and improved disturbance rejection that allows higher track density than those of single-stage HDDs [1–6]. Other DSA systems also include the dual-stage machine tools [7], macro/micro robot manipulators [8], XY positioning tables [9], and wafers alignment in microlithography [10]. Furthermore, a comparative study of DSA systems using micro-electro-mechanical-system (MEMS) microactuators is reported in [11,12].

According to the motion type, DSA systems can be categorized into two broad classes: linear and rotary. In some applications such as [7,9], linear DSA systems are used to carry out linear movements of the workpiece rapidly and accurately. However, in other applications such as [1,8], rotary DSA systems are needed to cooperate with other parts to accomplish the task. In these cases, either the angular displacement or the tangential displacement is typically the controlled variable. Thereby, the selection of actuators and the design of the flexure guidance considerably differ from those for linear DSA systems. For example, the suspension-actuated dual-stage HDDs [3] are typically configured by placing two piezoelectric (PZT) elements between the suspension and the arm to provide a secondary fine actuation of the read-write head in the off-track direction. In HDDs, the flexure beam that carries the read-write head is thin and lightweight to meet the requirements of high seeking speed and compact size. Due to the relatively small actuation force and stroke, the two PZT elements are adhesively bonded to the baseplate hinge. In this paper, we concentrate on the design and control of a rotary DSA positioner that can potentially apply to micro-assembly stations [13], micro-scanners [14] and surface inspection devices and microscopy [15]. Unlike the HDDs, these applications generally require a larger actuation force and stroke to displace the load at the platform. For this goal, we make the flexure beam have a larger dimension and employ a PZT stack actuator that offers a much larger actuation force and stroke. In this case, adhesive bonding cannot guarantee a firm attachment of the PZT surfaces to the beam. Instead, we should consider the mechanical preload on the PZT and the preload setting is carefully selected to guarantee the movement consistency between the beam and the PZT.

PZT tube scanners [16] are widely used in most commercial atomic force microscope (AFM). However, they have typically a low first mechanical resonance frequency of a few hundred Hertz and travel range up to 100 μm [17]. The DSA positioner we report in this paper has a much larger travel range up to 73 mm and a higher resonance frequency (1.12 kHz) that allows a wider

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