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Identification of micropositioning stage with piezoelectric actuators

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ABSTRACT

In this paper, a two-step identification method for a micropositioning stage with piezoelectric actuator is proposed. It is noted that one of the difficulties encountered in identification is that both input and output of the actuator embedded in the stage cannot be measured directly. Moreover, hysteresis existing in piezoelectric actuators is a non-smooth complex nonlinearity. In the proposed modeling method, a sandwich model with hysteresis is used to describe the performance of the micropositioning stage with piezoelectric actuator. In this modeling architecture, the input linear submodel is utilized to describe the behavior of preceded amplifier with filtering circuit, which provides electrical voltage to the piezoactuator, and the output linear submodel is employed to depict the flexural hinge with load, respectively, while a Duhem function embedded in between the input and output linear submodels is employed to describe the hysteresis characteristic of piezoelectric actuator in the stage. At the first step of the identification procedure, a special excitation input is implemented to excite the stage to decompose the hysteresis into a monotonic polynomial within a certain region. Then, the parameters of linear submodels are separated and estimated. Subsequently, at the second step, an input signal that can fully excite the system within the operation region is implemented to excite the stage. Based on the previously estimated linear submodels, both input and output of the piezoactuator are estimated. Then, in terms of the estimated input and output of the piezoactuator, the parameters of the hysteresis submodel are estimated. Finally, experimental results are presented to verify the proposed method.

1. Introduction

In a micro-positioning stage (MPS), piezoeloectric actuator (PEA) is often used to drive flexural hinge and load directly due to PEAs have the characteristic of high stiffness, nanometer displacement resolution, large bandwidth, and fast response [1,2]. Presently, the MPS has become a very popular precision device used in ultra-precision manufacturing and mechatronic systems such as scanning probe microscopy, biological manipulator and atomic force microscope etc. [3,4,5,6,8,9,24]. In order to realize ultra-precision positioning control in the MPS, the model based control strategies are usually the useful options. Thus, modeling the behavior of MPS is an important issue in the design of model based control strategy. In the modeling procedure of MPS, one of the barriers encountered is that both input and output of the piezoelectric actuator

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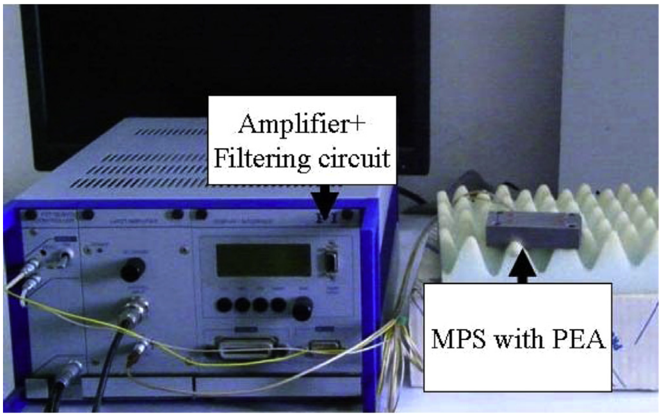

Fig. 1. Experimental setup of micropositioning stage.

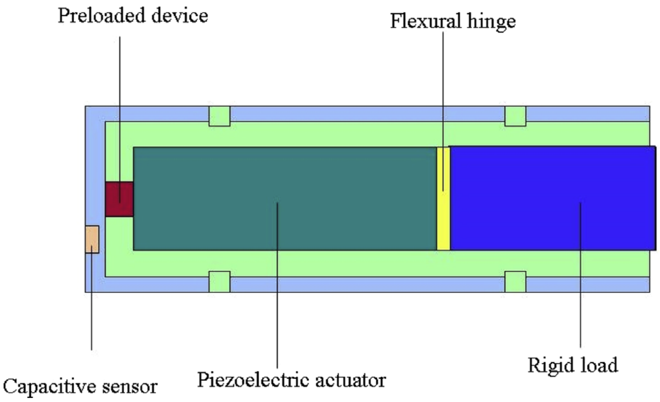

Fig. 2. Diagrammatic sketch of the structure of micropositioning stage.

cannot be measured directly since only the displacement sensor is installed to measure the displacement of load. Of course, installing more sensors to measure the input and output of the actuator is usually not considered due to the reason of cost reduction. Therefore, it is necessary to consider how to reconstruct the input and output of the embedded actuator to estimate the parameters of hysteresis submodel describing the characteristic of piezoelectric actuator. Another issue should be mentioned is that the hysteresis inherent in piezoelectric actuator is a non-smooth and dynamic nonlinearity varying with input rate. Thus, the identification scheme should also consider the features of non-smoothness and nonlinear dynamics existing in the system.

In Fig. 1, a micro-positioning stage with a piezoelectric actuator is illustrated. Moreover, the corresponding diagrammatic sketch of the structure of micropositioning stage is shown in Fig. 2. In the stage, the amplifier with filtering circuit providing electrical voltage to the PEA can be described by a linear dynamic submodel, and the flexural hinge with load driven by the PEA can also be depicted by another linear dynamic submodel. Meanwhile, the PEA embedded between the amplifier with filtering circuit and flexural hinge is described by a rate-dependent hysteresis submodel. Hence, a so-called sandwich model with hysteresis shown in Fig. 3 is implemented to describe the characteristic of MPS. In Fig. 3, both $L_1(\cdot)$ and $L_2(\cdot)$ are linear dynamic submodels, representing the amplifier with filtering circuit and flexural hinge with load, respectively, whilst $H(\cdot)$ is a nonlinear submodel employed to describe the hysteresis existing in the PEA. Moreover, both $w_1(k)$ and $w_2(k)$ are internal variables which represent the input and output of PEA in the stage, which cannot be measured, directly.

Although there have been some publications on the topic of identification of sandwich systems, it is rare to find published literatures to reveal the methods on identification of sandwich systems with embedded non-smooth hysteresis. For example, Dong and Tan [10] proposed an identification method for sandwich system with backlash but the properties of hysteresis are more complicated than those of backlash, while Xie et al. [24] proposed a modeling method for sandwich systems with hysteresis. In this modeling method, a neural network based on an expanded input space was used to describe hysteresis embedded in the system. Obviously, neural network based model is usually complex in architecture and, sometimes, may not be convenient for system analysis and controller design. Hence, it is necessary to build a relatively simpler model of MPS, which is more convenient for identification and controller design.

On the other hand, there have already existed different models for describing features of hysteresis, such as Preisach models, modified Preisach models [11–13], and Prandtl-Ishlinskii (PI) models [18,8]. Those hysteresis models mentioned are