Design and Experimental Investigation of a 2-DOF Planar Micro-Positioning Table

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ABSTRACT

This paper presents the mechanical design and experimental characterization of a 2-DOF serial flexure-based micropositioning table. The cascade mechanical structure is proposed to implement planar motions of the moving platform. In order to increase the stroke of the moving platform, a lever mechanism is designed to amplify the displacement of the piezoelectric actuator. The finite element method is utilized to analyze the mechanical and thermal characteristics of the proposed 2-DOF micropositioning table. The WEDM (Wire Electro-Discharge Machining) technique is used to manufacture the prototype of the micropositioning table. A number of experimental tests have been conducted to investigate the characteristics of the developed system.

Keywords: Dynamics, Finite Element Method, Micropositioning Table, Piezoelectric Actuator, Wire Electro-Discharge Machining (WEDM)

1. INTRODUCTION

With the development of modern science and technology, the nanometer positioning technology is urgently needed in many research and frontier technological domains such as aerospace technology, micro-electricity engineering, measurement science and technology, optics and light electronic engineering, precision engineering, bioengineering and nanometer science and technology (Kim & Gweon, 2012; Tian, Shirinzadeh, Zhang, & Alici, 2009; Polit & Dong, 2011; Dalvand & Shirinzadeh, 2012; Yong, Aphale, & Moheimani, 2009). This
makes micro/nano positioning and manipulation to be one of the key technologies of the frontier science and engineering fields. In the nanometer science and the technology domains with vigorous development at present, the nanometer positioning technology has close relationship with the SPM (Scanning Probe Microscopy), light etch and precision manufacture technologies and is becoming the key technology of the electronic chips, computer digital storage and high-precision parts manufacture (Liaw & Shirinzadeh, 2008; Zhang, Chetwynd, Liu, & Tian, 2006; Jia, Tian, Zhang, & Liu, 2011; Liaw, Shirinzadeh, & Smith, 2007; Yong, Liu, & Moheimani, 2010). The nanometer positioning technology has become the foundation of nanometer measurement and atom manipulation engineering research and for future industrial applications.

In the existing micro-positioning technology, the sliding and rolling ball guides are usually utilized to form the positioning mechanisms. Due to the backlash and mechanical friction, the positioning precision cannot reach to nanometer level. Though the air-supporting guide can achieve nanometer level positioning precision, the high cost and large volume limit the use of such approaches. However, the mechanical micro-positioning actuator cannot reach up to nanometer level positioning precision due to the mechanical gap, frictional force and creep (Bhagat, Shirinzadeh, Tian, & Zhang, 2013; Yong, Moheimani, Kenton, & Leang, 2012). Flexure hinge is a kind of new elastic guide form. This kind of guide has the characteristics of no friction, no backlash, smooth motion and manufacture simplicity, which make it suitable for nanometer level positioning domain (Qin, Tian, Zhang, Shirinzadeh, & Fatikow, 2013; Tian, Zhang, & Shirinzadeh, 2011). The piezoelectric actuator becomes the ideal micro-positioning parts due to structural compactness, high resolution, control simplicity and no heat generation characteristics (Tian, Shirinzadeh, & Zhang, 2010). It is the effective method to implement nanometer level positioning by using the flexure hinge as elastic guide and piezoelectric actuator as driving unit.

Recent research efforts have been directed towards mechanical design and characterization of 2-DOF planar flexure-based mechanisms (Yao, Dong, & Ferreira, 2007; Li & Zu, 2012; Tian, Shirinzadeh, Zhang, & Zhong, 2011). A number of 2-DOF micropositioning stages have been developed. The conceptual designs of such mechanisms are proposed and investigated. There are generally two categories of mechanical configurations to fulfill the requirements for planar positioning, that is, parallel kinematic mechanism and serial kinematic mechanism (Tian, Shirinzadeh, & Zhang, 2010; Shen et al., 2008). Although a parallel kinematic mechanism has many advantages including compactness, high stiffness, and large load carrying capability, the cross axis coupling and complex kinematic modeling are the main factors constraining its practical applications (Shirinzadeh, Bhagat, & Tian, 2011; Qin, Shirinzadeh, Tian, & Zhang, 2013). There are a number of research efforts dedicated to solving the above problems. The optimal design for realizing the kinematic decoupling of the motion axes has been investigated, and further the advanced control methodologies have also been studied to eliminate the coupling between the axes (Tian, Shirinzadeh, & Zhang, 2009; Liaw & Shirinzadeh, 2008). These proposed methodologies have reduced the coupling phenomena of parallel kinematic mechanism to some extent. However, there still exists motion coupling. As the mechanical optimal design only concentrates on the flexure hinge structure, thus when the piezoelectric actuators are installed at the flexure hinge mechanism, the entire system becomes an asymmetric structure. Thus, it is unavoidable to induce the motion coupling between different axes. The serial kinematic mechanism can overcome the shortcoming of the motion coupling of the parallel mechanism. Thus, it can be used to implement motion with high decoupling capability when the dynamic response is not a crucial issue during the positioning.

This paper presents the mechanical design and experimental characterization of a 2-DOF serial flexure-based micropositioning table.
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