Design and Optimization of Flexure-Based Micro-manipulator for Optics Alignment

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Abstract

This paper presents the development of a novel flexure-based micromanipulator for the alignment of optical components (Figure 1). The realized device is based on a six-axis parallel mechanism and piezo-positioners using stick-slip principle and providing nanometre resolution. Results of this paper show that the flexure-based design allows realizing nanometre steps with the moving platform in all axes.

1 Introduction

Laser technology had a large impact on industrial and everyday applications within the last decades. The increasing demand for laser systems requires automation of manual alignment and assembling processes to provide low cost high quality solutions. In complement to existing robot assembling systems like SCARA kinematics with large workspaces and low positioning accuracy, manipulators for precise component alignment with six degrees-of-freedom are necessary.

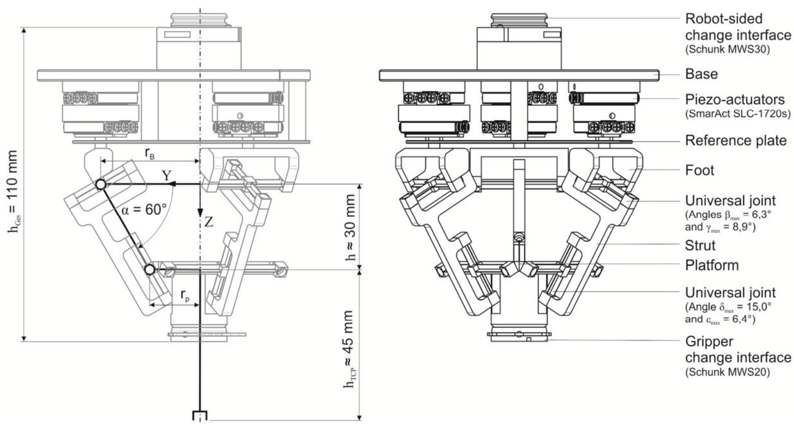

Figure 1: Design of six-axis micromanipulator

For this purpose, a symmetric, hybrid serial-parallel structure has been chosen that consists of three inextensible struts which connect three non-collinear points of its moving platform to its base. The motion of the manipulator is obtained by moving the lower ends of the struts on the base plane by means of three identical trays [1]. This strutucture is analysed in terms of geometrical influences on relevant performance characteristics, such as stiffness, singularities, workspace and transmission behaviour. The results are used to develop a systematic, graphical optimization technique for the parallel strucutre. For the flexure design joint angles and deformation forces are derived. Two universal joints were integrated in the kinematic chains instead of revolute and spherical joints presented in an earlier paper [2]. A method was developed to miniaturize the micromanipulator for a given workspace by optimization of flexures considering results of fatigue test for the joints.

2 Flexure hinges

The mathematical analyses resulted in required joint displacements of more than ±15°. For such large displacements a special type of flexure design has been chosen that differs from the wide-spread and well-known notch type joints or leaf springs. The chosen flexure type is a torsional joint with cross-shaped cross section (Figure 2) which generates pure rotational motion with widely reduced axis drift as well as a superior off-axis stiffness compared to many other types of flexure designs [3] [4]. It has further been optimized to achieve the best performance in terms of precision of motion and off-axis stiffness.

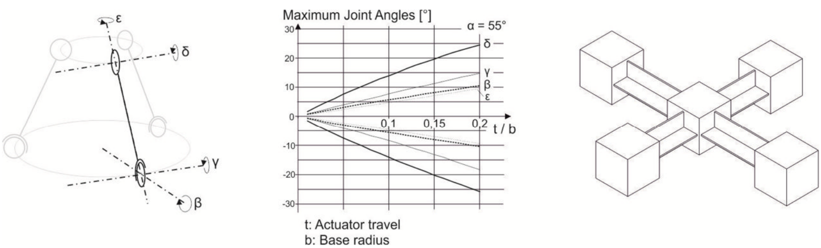

Figure 2: Influence of geometric parameters on maximum joint angle (left side); design of universal joint (right side)

Detailed results of the flexure design include the comparison of analytical calculations with numerical simulations (stiffness and stresses) as well as experimental fatigue tests to find an optimum design within the given constraints. As a part of the micromanipulator design both optimization methods have been integrated considering resulting space restrictions and drive specifications.

3 Workspace

The achieved overall size of the micromanipulator is Ø 115 mm × 110 mm (Figure 1) for a coupled workspace of ±1 mm in XYZ and ±1° in ΨΘΦ (Figure 3) and a compliance of the structure in vertical direction of 2.5 µm / N.

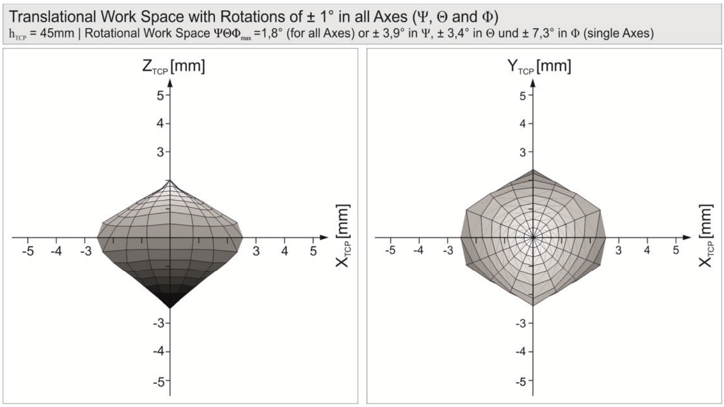

Figure 3: Translational workspace

4 Motion resolution and repeatabilty

The repeatability and the resulting motion resolution (Figure 4) of the compliant mechanism have been characterised by means of interferometer measurements. The bidirectional repeatability of the micromanipulator is around 50 nm.

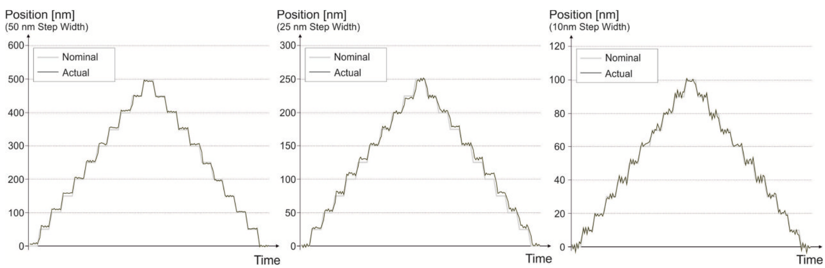

Figure 4: Motion resolution measurements

5 Conclusion

The presented six-axis manipulator design was optimized for assembling various optical laser components e.g. FAC lenses or laser resonators. Piezo-positioners and flexure hinges without hystersis effects provide highly precise motion of the moving platform in nanometre resolution.

In addition to the presented manipulator a flexure-based micromanipulator with three degrees-of-freedom was developed (Figure 5). These degrees-of-freedom are tip, tilt and piston motion of the moving platform. The device has a centre camera for component detection, a clamping unit for fixation of the moving platform and the hinges' protection for automated gripper exchanges. Its kinematical concept was presented by Tahmasebi [5]. Reducing the amount of actuators causes economic advantages for applications which require only three degrees-of-freedom.

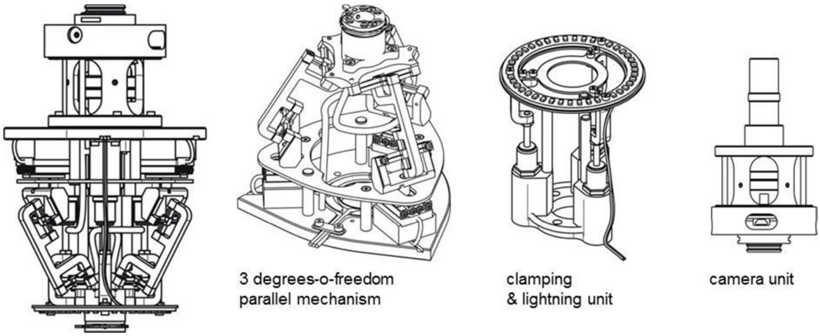

Figure 5: Modular design of three-axis micromanipulator

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