Design and construction of a novel assisted tool-holder

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Abstract

This paper presents a novel design of an Assisted Tool-holder (ATh) for ultra-precision single point diamond machining. The combination of a piezoelectric actuator to produce displacements, a non-contact capacitive sensor to accurately measure these displacements and a PID control system that maintains the accuracy of the displacement of the tool actuator ensures the quality of machining. Also, the design complies with the principle of symmetry and makes Abbe offset as small as possible. Backlash is avoided with the use of flexures at the operating range of 0-30 µm. Finite Element Method (FEM) analyses including strain stress due to forces acting on the system is employed. Fatigue analysis was performed to predict the lifetime of the ATh, and, finally, nodal analysis was performed to predict the natural frequencies of the system. The quality of the model was accomplished by optimizing the mesh according to the Skewness Criterion. Analyses took into account the reaction force of the flexure on the actuator due to the maximum displacement of 30 µm. The results of preliminary simulations showed that the ATh meets all the requirements of resolution, frequency response and compactness.

1 Introduction

Most experiments concerning micro and nano-positioning rarely meet a real application in precision engineering [1]. On the contrary, isolated tests have been done without control of the cutting force and designs seldom follow any evaluative mechanical principle (fatigue, effects of stress-strain response).

An example of a tool holder designed to achieve a maximum displacement of 7.5 µm at 100 Hz is described in [2]. In order to increase the displacement of this actuator, an amplifier was incorporated into the piezoelectric mechanism and the displacement was increased to 432 microns, compromising however the fatigue life. An interesting study on stiffness in three directions (x, y, z) of a fast tool servo is presented in [3].

This work aims to design an Assisted Tool-holder using Ansys® FEM analysis simulation tools ensuring the model's effectiveness by the Skewness criterion and checking the reaction forces caused by a maximum displacement of 30µm.

2 ATh design

The prototype of the Assisted Too-holder, ATh, was designed and constructed as shown in Figure 1. The device is composed of 6 main parts. A flexural bearing of the monolithic type which generates pre-loading and restoring force, a sensor mount, an actuator mount, a tool-holder, a piezoelectric actuator and a capacitive sensor. The design adheres to the principles of alignment and symmetry and contains no moving parts. Also, the piezoelectric actuator is firmly attached to the tool-holder, eliminating noises and imperfect contacts.

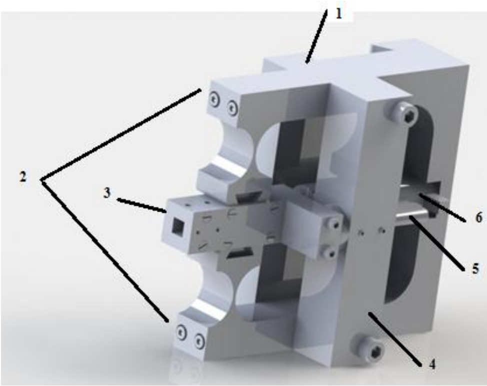

Figure 1: Schematic view of the ATh parts: (1) actuator mount, (2) flexural bearings, (3) tool holder (4) sensor mount, (5) capacitive sensor, and (6) piezoelectric actuator.

3 Generation and optimization of the FEM mesh and results

The Skewness criterion was used to evaluate and optimize the effectiveness of the mesh. Its main function is to quantify how close an element in the mesh is to the ideal, so it quantifies the distortion of the actual pattern of the element. This method is defined as:

$$\text{Skewness} = \frac{(\text{optimal size of element}) - (\text{element size})}{(\text{optimal size of element})}$$

The average skewness value of the elements was 0.527. This criterion ranges from 0 to 1 (excellent to bad, respectively). Therefore this mesh can be considered good. Special attention was given to contacts considered critical (flexures/tool-holder) to refine the mesh, as observed in Figure 2. Entire mesh study is needed to ensure the fidelity of the model relative to the actual model.

Reaction force value corresponds to a displacement of 30 μm and 0.5 mm spring thickness in aluminum alloy 7075. Figure 3 shows the average von misses stresses caused by this displacement.

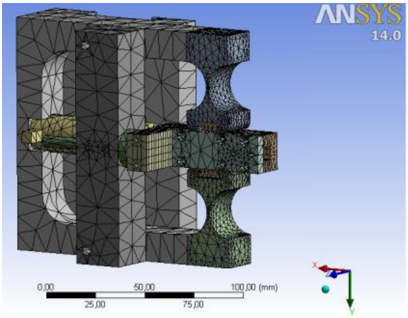

Figure 2: Mesh refinement.

Simulation of nodal frequencies showed the first natural frequency to be above 1 kHz for 1.5 spring thickness. Fatigue analysis predicted a lifetime of 10^{11} and 10^{10} for spring thickness of 1.5 and 0.5, respectively. A simple, symmetric design proved itself to attend the requirements of fatigue life and frequency response.

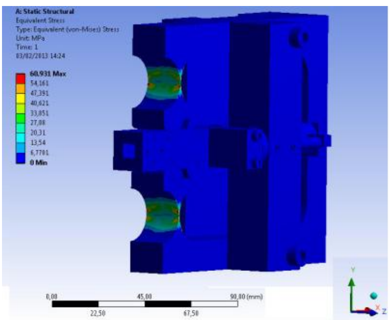

Figure 3: Von Misses stress

Table1: Results of life and natural frequencies

Material	Thickness of spring (mm)	Life (cycles)	Natural frequency		
			1st	2nd	3th
Aluminium 7075	1,50	10^{11}	1008,8	1535,4	1742,8
	0,50	10^{10}	754,7	932,1	1297,3

4 Conclusions

An assisted piezoelectric tool holder was designed and constructed. An optimized mesh (skewness criterion) Finite Element model was used to predict displacement, lifetime, stress and natural frequency. Simulations showed that the FEM model and the prototype attend all requirements of resolution and frequency response.

References:

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