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DESIGN AND CONSTRUCTION OF A NOVEL ASSISTED TOOL-HOLDER

Laercio Javarez Junior
Universidade Tecnologica Federal do Paraná. Av. Monteiro Lobato, km04. Ponta Grossa-PR
laerciojunior@utfpr.edu.br

Jaime Gilberto Duduch
Universidade de São Paulo. Escola de Engenharia de São Carlos, Av. Trabalhador São Carlense, 400. São Carlos-SP
jgduduch@sc.usp.br

Andre Motta Gonçalves
Universidade de São Paulo. Escola de Engenharia de São Carlos, Av. Trabalhador São Carlense, 400. São Carlos-SP
amgoncal@hotmail.com

Jose Antonio Otoboni
Universidade de São Paulo. Escola de Engenharia de São Carlos, Av. Trabalhador São Carlense, 400. São Carlos-SP
branco@opto.com.br

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.*

Keywords: *Assisted Tool-holder, Ultra-precision, Piezoelectric, Control System*

1. INTRODUCTION

Ultraprecision machining has become increasingly important to manufacturing and world economy. Led screens, amoled, mechanical components and military equipment are just some of the applications involving this technology. One way to ensure the machining quality is the use of assisted displacement of the tool in single point diamond turning of free-form surfaces. Most assisted tool-holders use piezoelectric actuators to promote high accuracy and high frequency displacements.

Most experiments concerning micro and nano-positioning rarely meet a real application in precision engineering (Li, 2010). 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 (Kim, 2004). 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 (Gan, 2007). A study relating the condition of contact between the actuator and the rigid part of a fast tool (and its stiffness) with the fatigue life, using fem, is described in (Tian, 2009).

Huo and Cheng (2008) in their paper showed that using the actuator frequency equal to the first natural frequency of the tool-holder results in decreased effectiveness of the piezoelectric actuator.

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. The design combines dynamic behaviour and static analysis of each of the components of the tool-holder including the piezoelectric actuator and a capacitive sensor.

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2. ATH DESIGN

The prototype of the Assisted Tool-holder, ATh, was designed and constructed as shown in Fig. 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.

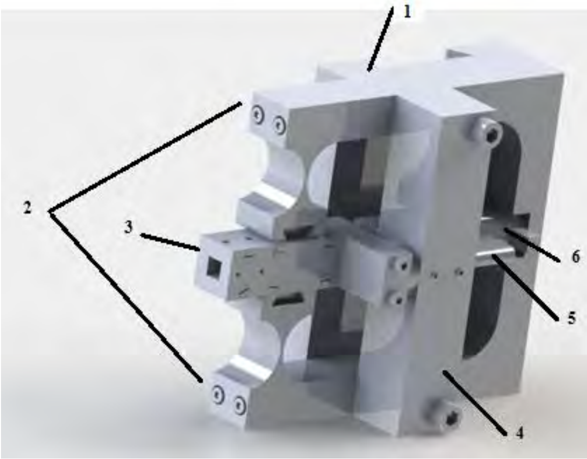

Figure 1. Schematic view of the ATh parts: (1) actuator mount, (2) flexural bearings, (3) tool- holder (4) sensor mounted, (5) capacitive sensor, and (6) piezoelectric actuator.

The design criteria and requirements are:

- Versatility to change tools
- Symmetry
- Elastic recovery
- Natural frequencies
- Range (30 µm)
- Fatigue

2.1. Generation and optimization of the FEM mesh and results

For areas of joints and contacts that may require more effort from the material, it is appropriate make a mesh refinement located.

Ansys® has various levels to specify the amount of refinement to be done. The value of this level must be an integer of 1 to 5, where a value of 1 refinement provides minimum and a maximum value of 5. The level two used joints represents 1/3 the size of the edge finite element created. Thus it has more data from stress and strain per unit area. (Fig. 2)

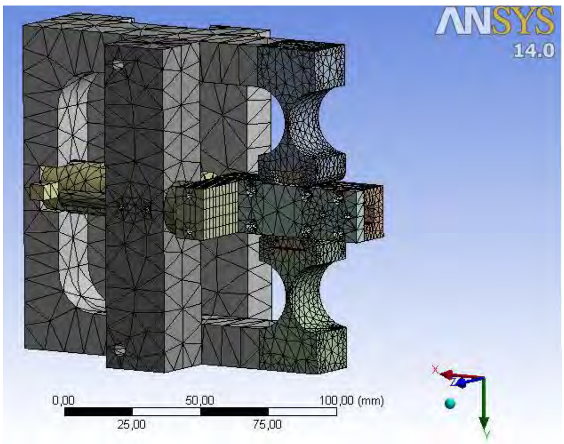

Figure 2. Refinement located the springs and interfaces with tool support

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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:

$$\text{Skewness} = \frac{(\text{optimal size of element}) - (\text{element size})}{(\text{optimal size of element})} \quad (1)$$

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 Fig. 3. Entire mesh study is needed to ensure the fidelity of the model relative to the actual model.

The elements with sizes greater than 0.63 are concentrated in the fixed base and PFA sensors and actuators, which does not reflect importance because areas are considered low risk of collapsing due to low voltage values.

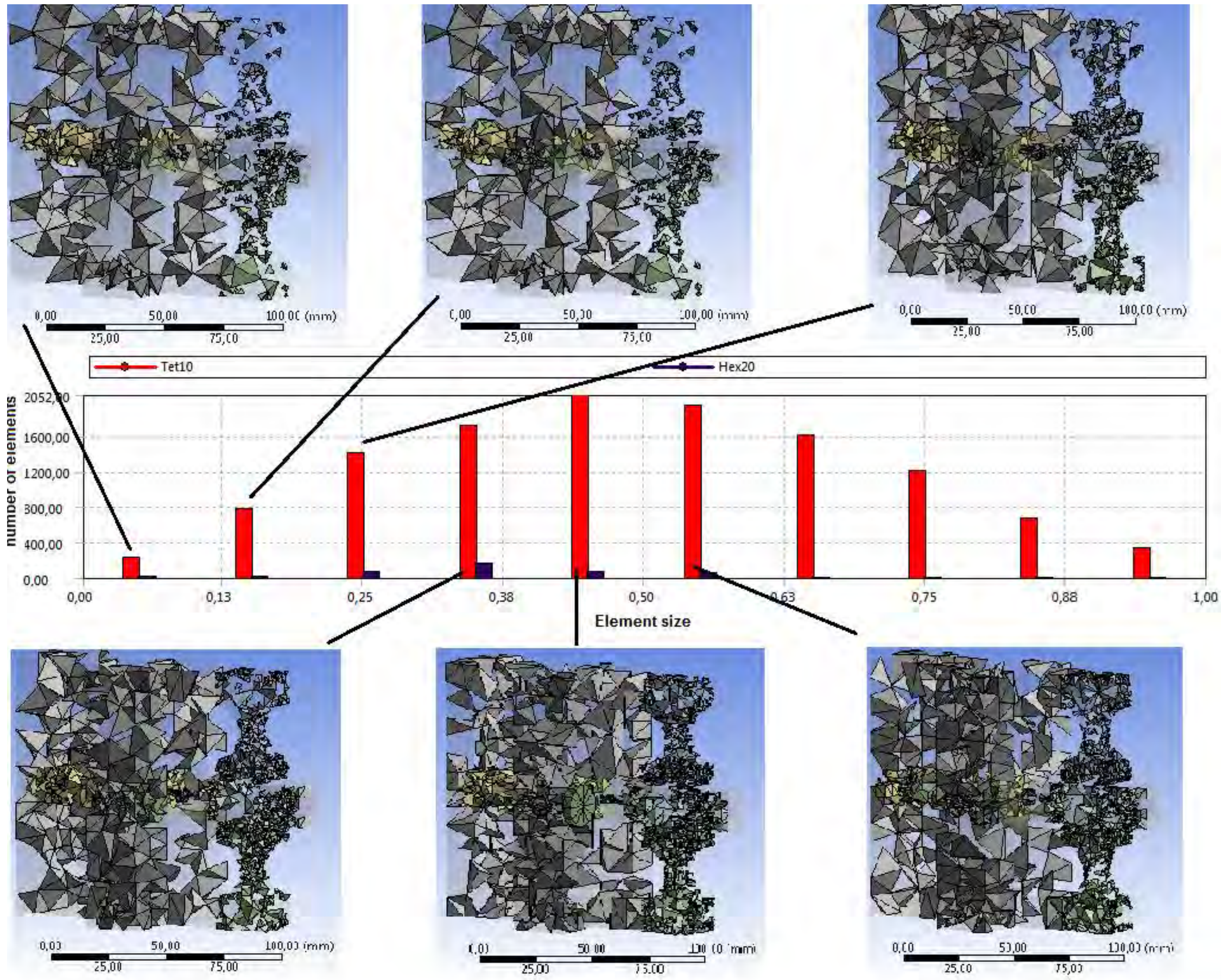

Figure 3. The central graph shows the quantity of elements in the model of Tool-Holder.

2.2. Static Analysis

Reaction force value corresponds to a displacement of 30 μm and 0.5 mm spring thickness in aluminum alloy 7075. Fig. 4 shows the average von misses stresses caused by this displacement.

Simulation of nodal frequencies showed the first natural frequency to be above 1kHz 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.

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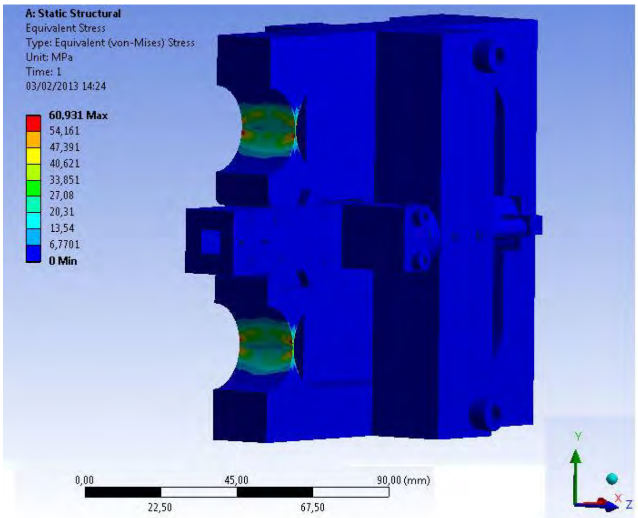

Figure 4. Von Misses stress

2.3. Reaction force of the spring

The design of coupling between the springs and tool support was based on the style swallowtail. This type of fixing model generates continuous contact between the two parts, but the rotational displacement caused by the linear movement of the tool-holder stresses generated on the basis of the fixation, causing "extra stresses." On the other hand instead of these stresses cause problems in model help to maintain the tool-holder always aligned. In Fig. 5 we observe the stresses caused by a displacement reaction of 30µm to 7075 aluminum.

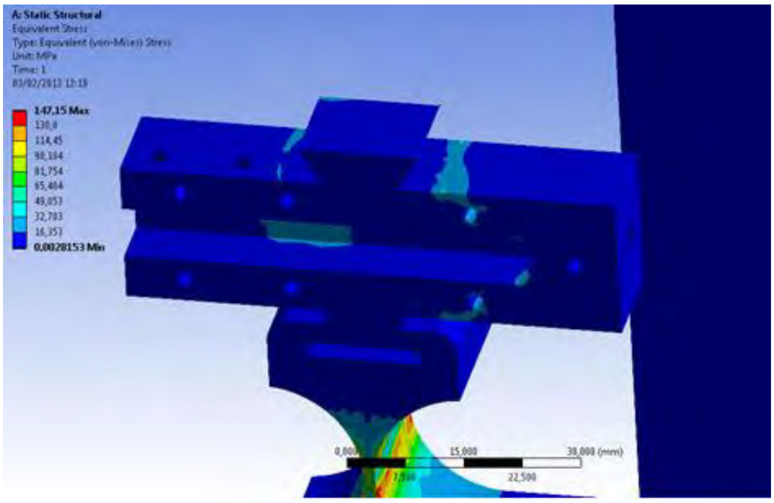

Figure 5. Extra stress on the tool-holder

This type of "extra stress" seen in Fig. 5 does not cause any deformation of the tool-holder. The Fig. 6 shows the directional deformation in the y-axis of the tool-holder, at the location where the extra operating stresses can be noticed values close to 0 deformation. All components that did not appear in the figure are activated in invisible mode.

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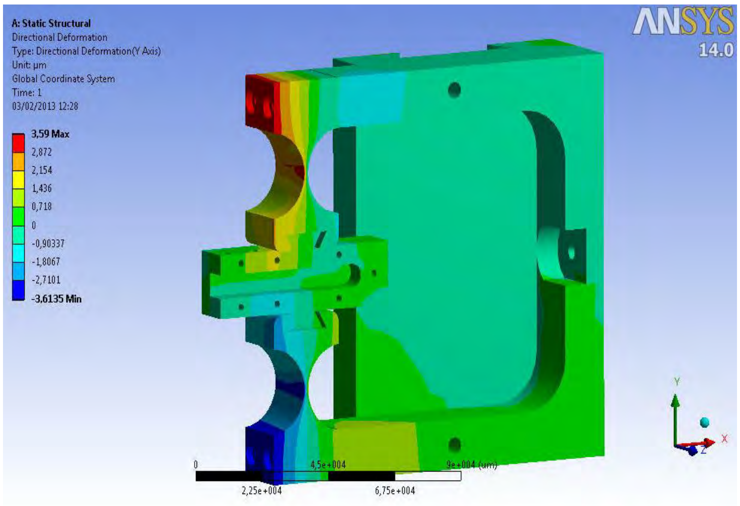

Figure 6. Directional deformation on the y axis of the PFA

2.4. Dynamic Analysis

Fatigue analysis has been performed to determine the life in cycles of all components of the Tool-Holder. A 30 µm maximum tool displacement was considered. The Morrow theory was used adopting the complete reverse mode n the simulation. Results showed that the life was of the order of 10^{10} for all parts of the Tool-Holder, including the flexures.

Nodal frequencies have been determined and are presented in Table 1. Such an analysis is necessary since the actuator may be required to perform at high frequencies during diamond turning of non rotational features. Table 1 shows the first three natural frequencies and life in cycles of a Tool-Holder fitted with a 1.5 mm flexure and a 0.5 mm flexure.

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

3. CONCLUSIONS

Aluminum showed to be an excellent material for the body and flexures both in terms of static and dynamic behavior. The design principles of symmetry and alignment have been used and simulations showed that no stresses (nor strains) are found other than in the flexure, for the maximum tool displacement of 30 µm. This displacement generates a reaction force of only 23% of the full load capacity of the piezoelectric actuator. Fatigue analysis results showed that the life may be considered infinite. The first natural frequency is larger than 900 Hz for the 1.5 mm flexure which is considered satisfactory.

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