Concept for a Miniaturized Machine-Tool-Module for the Manufacturing of Micro-Components Operated at its Resonance Frequency

C. Oberländer[1], J.P. Wulfsberg[1]
[1]*Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg, Germany*

Carsten.Oberlaender@hsu-hh.de

Abstract

The operation of conventional machine tools at resonance frequency is generally avoided. High amplitudes generated by the mechanical resonance cause surface errors on the workpiece and the machine tool can be damaged. This paper presents a new concept for a machine-tool-module (MTM) which is operated at its resonance frequency. It consists of a piezo actuator, a displacement amplifier and the tool itself. By excitation the displacement amplifier at resonant frequency, very large amplitudes at the tool can be achieved. The emphasis of this paper lies on the analysis of the dynamic behavior of the displacement amplifier at its resonance frequency. The results are compared with the static operation of the amplifier.

1 Introduction

The use of small machine-tool-modules (MTM) enables the application of new technologies and functional principles, which are not suitable for the use in larger machine tools. The basic idea behind the presented concept is to operate the MTM at its resonance frequency, thus large amplitudes can be achieved to move the tool in z-direction. The feed movement of the workpiece in x- and y-direction is realized by the feed unit based on flexure systems, which has already been presented at euspen [1] within the framework of Square-Foot-Manufacturing [2]. The MTM can be used for manufacturing processes such as micro-cutting of thin foil or sheet, micro-structuring of surfaces or minting. Unlike ultrasonic superimposed manufacturing processes (e.g. ultrasonic cutting or ultrasonic stamping), this machine concept only uses the amplified oscillation to move the tool in z-direction. There are no additional actuators needed to move the tool in z-direction. Moreover, an energetically favorable state predominates because of operating the structure at its resonance range. Energy is withdrawn from the system only by damping and the manufacturing process.

2 Design Concept

The machine-tool-module consists of an actuator for generating an oscillation, a structure for transmitting and amplifying the oscillation (displacement amplifier) and the tool itself.

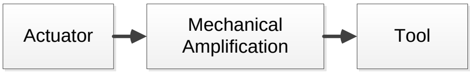

Figure 1: Concept of the Machine-Tool-Module

The oscillation is generated by a piezoelectric actuator. The amplitude of the oscillation generated by these kinds of actuators is typically in the range of 0-100µm at frequencies up to 20,000Hz. To make this kind of oscillation usable for tool movement, it must be transmitted and amplified.

The oscillation is transmitted and amplified by applying a transmission structure based on flexure hinges which is specially adapted to the respective manufacturing process. Flexure hinges, free of play, friction and wear, guarantee high dynamics combined with high accuracy. As a first approach a geometry inspired by [3] is used (Figure 2). Amplification is achieved in two stages: A pair of simple levers as the first stage, a flexural bridge as the final stage. By the combination of lever and frame solutions a highly stiff design with a rapid response can be achieved [3].

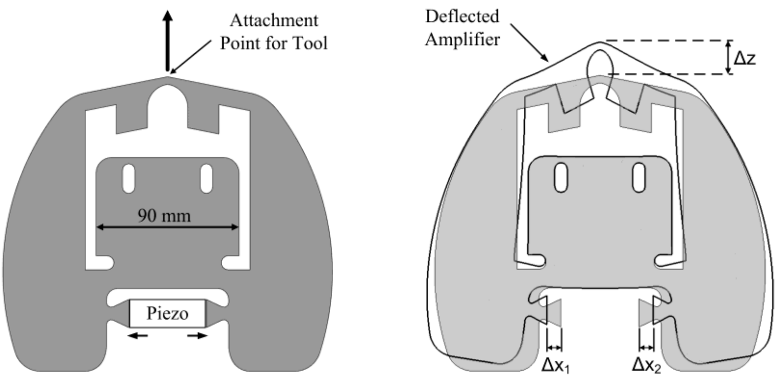

Figure 2: Displacement Amplifier

The mode shape of the transmission structure is used directly for moving the tool. By exciting the structure in its resonance range, maximum amplitudes are generated at the attachment point for the tool.

3 Simulation of Dynamic Behavior

3.1 Modal Analysis

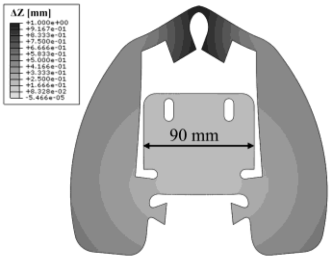

Figure 3: 7th mode shape at 1298 Hz

As a condition for further analysis a modal analysis of the amplifier geometry is performed. The first 20 eigen modes and the their respectiv mode shapes are calculated. Figure 3 shows the 7th mode shape at 1298Hz. This mode shape was chosen for further analysis. The attachment point for the tool oscillates with maximum amplitude in z-direction and the amplifier only oscillates in the x-y plane. For all simulations, the FEM software ABAQUS was used.

3.2 Static and Dynamic Analysis

The actuator expansion ΔX is simulated by a displacement boundary condition of the two contact surfaces between the actuator and the amplifier ($\Delta X = \Delta X_1 + \Delta X_2$). The output displacement ΔZ is measured at the attachment point for the tool (Figure 2). The ratio of these two displacements is the displacement gain ($\Delta Z/\Delta X$). Four different input displacements ΔX at three frequencies were analyzed. Table 1 shows the results of the analysis. The mean displacement gain in static mode is about 1.18, in dynamic mode at 150Hz about 2.04 and at resonance (1298Hz) 6.55 (Table1).

Table1: Displacement Gain in Static Mode and Dynamic Mode

	Static Mode		***Dynamic Mode 150 Hz***		***Dynamic Mode 1298 Hz (Resonance)***	
Input ΔX (µm)	Output ΔZ (µm)	Displacement Gain	Output ΔZ (µm)	Displacement Gain	Output ΔZ (µm)	Displacement Gain
10	11.7	1.17	20.4	2.04	66.1	6.61
20	23.6	1.18	40.9	2.05	128.6	6.43
30	35.3	1.18	59.7	1.99	194.7	6.49
50	58.9	1.18	103.5	2.07	334.5	6.69

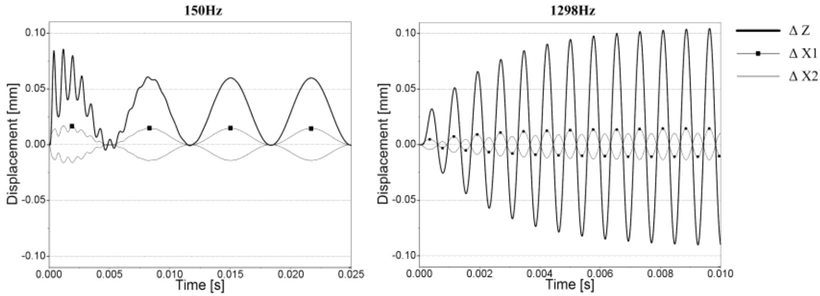

Figure 4: Displacement ΔZ, ΔX_1 and ΔX_2 at 150Hz/ 1298Hz (Resonance)

By excitation of the amplifier at resonance frequency a three times larger displacement ratio can be achieved. Figure 4 shows the displacement-time-graph for $\Delta X = 30\mu m$ at 150Hz and 1298Hz.

4 Conclusion and Outlook

The simulation has shown that the excitation of the amplifier in the resonance range leads to much larger amplitudes and displacement ratios. To make a statement on the technical feasibility of the concept further investigations are necessary. For the further development the influence of the attached tool and the manufacturing process must be considered and an appropriate control system has to be designed. The size and the influence of unwanted oscillation amplitudes in the X and Y directions must be examined and reduced. In addition, the resulting stresses must be determined and minimized by a geometry optimization process in order to maximize service life.

References:

[1] Kong, N., Grimske, S., Röhlig, B., Wulfsberg, J. P.: **Flexure Based Feed Unit for Long Feed Ranges: Concept and Design** In: Proceedings of the 12th euspen International Conference, Stockholm, June 2012

[2] Wulfsberg, J.P. , Kohrs, P., Grimske, S.; Röhlig, B.: **Square Foot Manufacturing - A new approach for desktop-sized reconfigurable machine tools,** Future Trends in Production Engineering - Proceedings of the WGP-Conference, Berlin, Germany, 8th-9th June 2011; Publisher: Neugebauer, R.; Schuh, G.; Uhlmann, E., 2012, Berlin

[3] Pozzi, M., King, T.: **Piezoelectric Actuators in Micropositioning**, Engineering Science and Education Journal 10 (1), pp. 31-36, 2001