Development of a mechanical amplifier considering the dynamic behaviour at resonance excitation

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Introduction

An analysis of today's manufacturing processes of micro parts reveals an inadequacy of machine size compared to workpiece size. The machine tools are often considerably larger than the workpiece that is to be manufactured. The modular machine tool approach "Square Foot Manufacturing" (SFM) tries to dissolve this discrepancy [1]. By miniaturizing the machine tool it is possible to apply new technologies and principles, which cannot be used in conventional machine tools. This generates technical, environmental and economic benefits. A concept for a new module within the framework of Square Foot Manufacturing was presented at the last euspen conference [2].

The module consists of a piezo actuator, a mechanical displacement amplifier and a tool. The amplifier is necessary to reinforce and transmit the movement of the piezo (max. 120µm). The new approach is to excite and operate the amplifier at one of its eigenfrequencies. This leads to a large gain factor of the amplifier and maximum amplitudes at the Tool-Center-Point. The amplifier is based on flexure hinges. Flexure hinges are free of play, friction and wear. This ensures high dynamics combined with high accuracy.

The use of mechanical amplifiers based on flexure hinges to increase the movement of piezo actuators is state-of-the-art. However, most of the systems are operated statically or quasi-statically [3]. If they are operated dynamically, excitation at an eigenfrequency will be avoided. Conceivable applications for the module are micro-cutting of thin foil or sheet metal, micro-structuring of surfaces or minting. The emphasis of this paper lies on the analysis and optimization of the dynamic behavior of the displacement amplifier at one of its eigenfrequencies.

1. Design of the Mechanical Amplifier

The amplifier is dynamically operated at one of its eigenfrequencies and should have specific dynamic properties (mode shape, amplitude, frequency), depending on the desired manufacturing task. The dynamic behaviour of a given system can be analysed very well. However, if the required dynamic properties of a system are known, there is no methodology by which an appropriate geometry can be generated. Thus for the design of a dynamic operated amplifier, especially in the resonant mode, there is no suitable methodology.

Therefore, the following procedure was adopted: First a basic amplifier geometry was created. Amplification is achieved in two stages: A pair of simple levers as the first stage, a flexural bridge as the final stage. By combining lever and frame solutions a highly stiff design with a rapid response can be achieved. This geometry was used as a starting point for further optimization process (Figure 1).

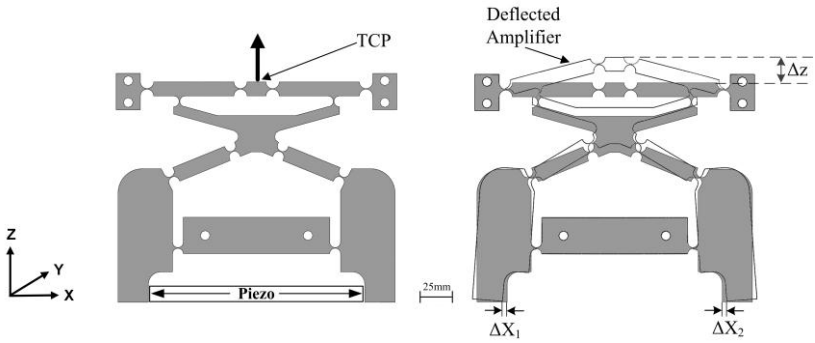

Figure 1: Displacement Amplifier

Subsequently the geometry was converted into a black box model. For this purpose, input and output factors as well as system boundaries were defined. The geometric parameters *a*, *b*, *α* and *t* were determined as input factors. Not influenceable/ constant input factors are, for example, material properties and the displacement of the piezo actuator. The gain factor of the amplifier ($\Delta Z/(\Delta X_1+\Delta X_2)$), the eigenfrequency of the desired shape and the maximal stress in the hinges were defined as output factors (Figure 2).

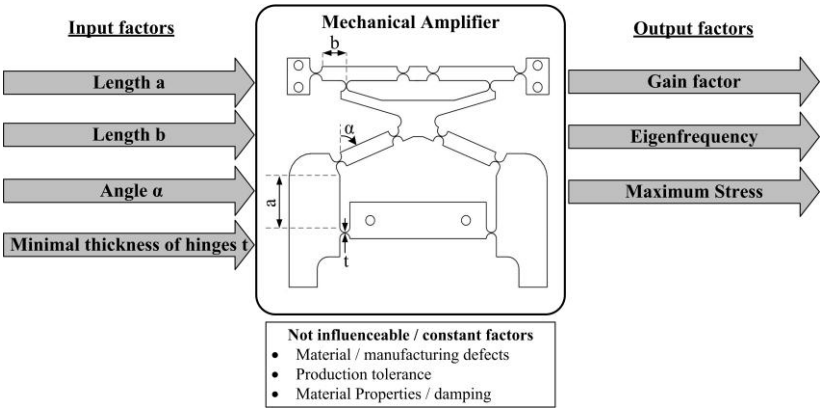

Figure 2: Black Box Model of the Amplifier

2. Simulation Study of Dynamic Behavior

To identify the cause-effect relationships of selected geometric properties on the dynamic behavior at resonance, a simulation study was carried out. The study is based on the black box model. To perform the simulation study as efficiently as possible, a simulation plan was created using Design of Experiments (DOE) techniques. The use of a Central Composit Design (CCD) allows the efficient determination of the quadratic correlations of the four input factors with only 25 simulation runs. In addition, the linear main effects and interactions of the four input factors can be determined.

For each simulation run, a modal analysis was conducted first to extract the eigenfrequency with the desired mode shape (Figure 1, Deflected Amplifier). In a subsequent direct-solution steady-state dynamic analysis the amplifier was excited with the calculated frequency to determine the dynamic behavior. The excitation was implemented with two displacement boundary conditions. For one, the vibrating amplitude (ΔZ) on the TCP was determined to calculate the gain factor of the amplifier. In addition, the maximum stress in the hinges was ascertained. This has a great impact on the service life of the amplifier.

The simulations were performed using the software ABAQUS. With the help of the identified cause-effect relationships an optimized amplifier can be designed which has the required dynamic behavior at resonance excitation. As an example, Figure 3

shows the effects of the input parameters *a* and *b* on the output parameters *eigenfrequency* and *gain factor*.

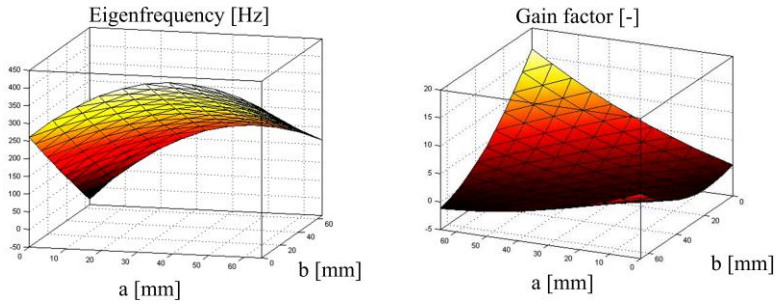

Figure 3: Simulation Results – Example of identified Cause-Effect Relationships

3. Conclusion and Outlook

For the design of a dynamically operated amplifier at one of its eigenfrequencies there is no suitable methodology. In general intuitive approaches are adopted. Using the approach shown here, it is possible to design an amplifier with desired dynamic characteristics. The performed simulations do not give any information about the reasons for the observed effect relationships (black box model). This is the subject of further research. The established model has already been verified by experiments. Further experiments are planned in order to increase the accuracy of the simulation model.

References:

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