Influence of production tolerances on the performance of a piezoelectric nanometer positioning system

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Keywords: Piezo, Motor, Resonant, Performance, Deviation, Production, Tolerances

Abstract

This paper handles about the influences of production tolerances on the performance of ultrasonic piezoelectric motors. To eliminate assembling and mounting tolerances from the modal experiments, the patented Leuven motor structure is redesigned into a sample structure. To enable modal measurements, an innovative experiment is constructed in which steal balls are launched to excite the sample structures. A generic code has been developed to determine the dominant production causes for these performance deviations.

1. Introduction

In the scope of the ever increasing accuracy of positioning systems, the Department of Mechanical Engineering at KU Leuven researches piezo-electrically driven integrated positioning systems [1-2]. Although these systems have many advantageous properties like high stiffness, high bandwidth, high power density and theoretically unlimited resolution and although these systems have already achieved impressive results, a few fundamental problems impede their final breakthrough.

The implementation of ultrasonic piezoelectric motors suffers from a shift of the resonant frequency, whose value has to be known to get maximal performance from the drive [3-5]. The resonant frequency is influenced by several parameters e.g. production tolerances, assembling tolerances, mounting tolerances, preload of the motor against the slider, internal generated heat and ambient temperature.

This paper handles about the influences of production tolerances on the resonant frequency. The influences of the consecutive steps during the production process differ from step to step. With sensitivity knowledge of the resonant frequency to these distinct production steps, guidelines for the production process can be relaxed or tightened where needed. This enables optimization of the production process towards performance of the produced piezo motors.

The modelling section describes an automated procedure. This automated procedure uses a parameterized finite element model of the considered Leuven piezo motor. The automated procedure calculates the influence of the production steps, by using the current production tolerances statistically.

The complementary experimental section validates the theoretical section. This section describes the isolation of the production tolerance influences from the other influencing factors (assembling tolerances, mounting tolerances, preload of the motor against the slider, internal generated heat and ambient temperature) for the experimental measurements. To enable this isolation, a temporary redesign of the Leuven motor is performed while conserving all conclusions for the patented design of the Leuven motor itself. A limited number of redesigned motors are produced. The influences are experimentally validated on these produced motors. To enable these measurements, an innovative excitation method is constructed.

2. Experimental section

Figure 1 represents a piezo motor designed at KU Leuven [6]. The motor consists of several separate produced components. After assembling these components, the motor is mounted in a test stand for a performance test. This measured initial performance differs significantly from motor to motor. These performance deviations are caused by resonance deviations due to production tolerances, assembling tolerances and mounting tolerances. The sample structure in figure 2 is a redesign of

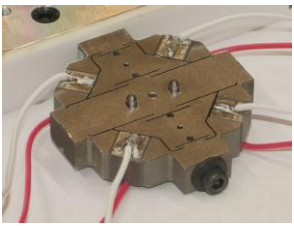

Figure 1: Leuven piezo motor

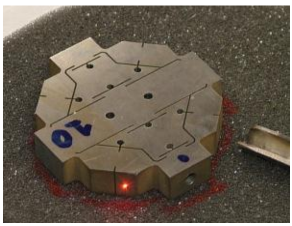

Figure 2: Sample structure designed to eliminate the assembling and mounting influences out of the modal measurements

the motor structure in figure 1, in such a way that only production influences remain, while assembling and mounting influences are eliminated. This sample structure is not deployable as a motor because the piezo stacks are not included, but the dynamic properties are similar to those of the Leuven motor. A set of ten such sample structures are produced for modal measurements. To enable these modal measurements, an innovative experiment is constructed as indicated in figure 3, in which steal balls with a diameter 2 mm are launched to excite the structure in the desired frequency range. The experimental results are shown to be highly repeatable.

3. Modelling section

Figure 4 presents a parameterized finite element model of the designed structure in figure 2. The parameters in the model correspond to the production misalignments. The parameters enable to simulate the resonance deviations stemming from the production misalignment. To obtain realistic parameter values, production tests are performed and identified using a CMM. The non-cross correlated relations between each independent parameter and the resonance deviation are simulated, resulting in a linearized sensitivity function for each parameter. Monte Carlo simulations result in the cross correlated sensitivity function between the parameters and the resonance deviation. A generic code has been developed to calculate and present these sensitivity functions. The simulation results match the experimentally measured deviations. In addition to the experiments, the simulations provide the possibility to determine the dominant causes. The simulations indicate that in this case the production process from drilling the central bolt hole is the main cause for the resonance deviations.

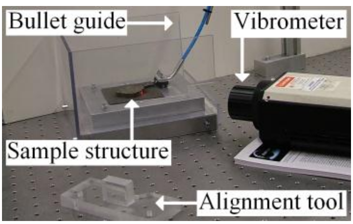

Figure 3: Innovative modal experiment launching bullets to excite the structure in the desired frequency range

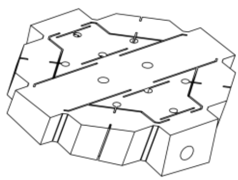

Figure 4: Parameterized model used in the generic code to determine the production influences on the motor performance

4. Conclusions

For the Leuven piezo motor, the performance deviations (resonance deviations) due to production deviations are simulated and experimentally verified. To enable the experiments, the motor structure is redesigned and an innovative test setup is constructed in which bullets are launched to excite the structure in the desired frequency range. The simulations indicate that, in this case, the performance deviation is mainly caused by the production process from drilling the central bolt hole.

A generic method is developed to determine the influences of the production tolerances on the motor performance and appoint the dominant causes. This provides a strategic advantage when considering alternative production processes and contemplating the current production processes.

Acknowledgements:

Research partly funded by PhD grants of the Institute for Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen).

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