Dissecting the dynamic response of an ultra-fast actuated mirror

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Abstract
The overall behavior of piezo-based actuators does not solely rely on the dynamic response of the piezo electric element itself. Both the packaging and the mounting conditions of the piezo contribute to the actuator's performance. Here, we used SmarAct's **PICO**SCAN Vibrometer to directly visualize the vibrational modes of the different building blocks of an ultra-fast actuated mirror. This dissection of the dynamic response allows to attribute particular resonance peaks to specific components of the assembly. The results can be exploited to control and to improve the design of actuators that operate under dynamic challenging conditions.

1. INTRODUCTION

A very simple actuator solely consists of a piezo material which is mounted onto a sample. The electrical excitation of the piezo brings in motion the sample at a desired frequency and amplitude. In many applications however, the piezo is not directly in contact with the actuated object as it has to be protected. This implies designing a housing in order to safely support the piezo while mostly leaving its dynamic response unchanged. Nonetheless, this remains a difficult task as each component of the assembly mechanically contributes to the overall dynamic response.
Finite element analysis can help to predict the influence of the contact boundary conditions on the dynamic behavior of the assembly (piezo and housing). Nevertheless, production tolerances and the exact mounting stresses are difficult to include.
As a consequence, the actual measurement of the vibrations of the assembly remains essential to properly characterize the performance of actuators and will help to further improve and control their design.
Here, we employed SmarAct's **PICO**SCAN Vibrometer to directly measure and visualize mechanical resonance modes of an ultra-fast actuated mirror, which consisted of an enclosed piezo and covered by a mirror. To this end, we investigated the top and bottom surfaces of the complete assembly and compared their individual frequency response with the one of the bare piezo that was mechanically disconnected from the support. The results emphasize the impact of the metal housing (mount and mirror) on the dynamic behavior of the piezo material.

2. METHODS

The experiments were performed on a standard **PICO**SCAN Vibrometer. The ultra-fast actuated mirror consisted of a piezoelectric ring chip (PA44LE, Thorlabs), with 515 kHz resonant frequency (free from load), glued in a titanium mount and covered by an independent titanium reflective mirror, Figure 1. All part of the actuated mirror are pierced at the center by a 3 mm diameter hole. The mount has two additional apertures of 2 mm diameter for the electrical wires. The whole assembly is itself mounted in a VA-steel stage. In the case of the measurement of the dynamic response of the bare piezo, the ring was lying on a 3.2 mm thick sorbothane sheet (SB12A, thorlabs). The softness of the rubber sheet ensures mechanical decoupling of the piezo from the support.

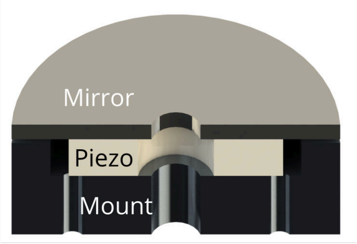
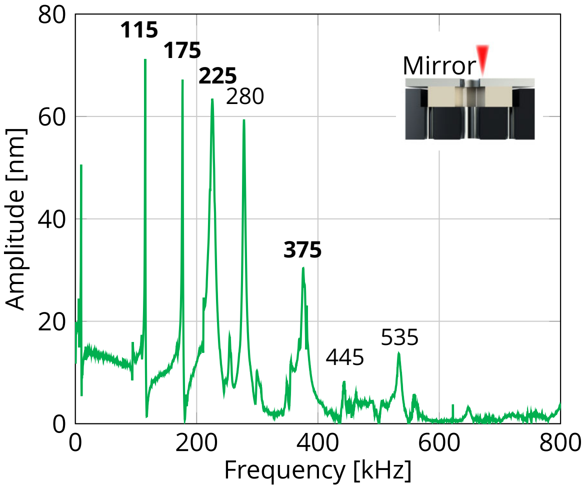


Figure 1. *Schematic of the ultra-fast actuated mirror. The piezo ring is glued on the polished titanium mirror while being also attached to the titanium mount. The actuation of the piezo bring in motion the mirror up to 2.5 MHz*

The experimental workflow was as follows:
- Record a 200 x 200 pixels microscopy image of the region of interest using the confocal principle of the **PICO**SCAN Vibrometer.
- Position the interferometer beam onto the inner edge of the centered annular disk and use the autofocus option to focus the laser.
- Drive the piezo ring with a linear sweep at constant amplitude from 10 kHz to 800 kHz using the function generator of the **PICO**SCAN Vibrometer. The measured displacements are Fourier transformed to show the amplitude in the frequency domain.
- Select a peak of interest in the amplitude spectrum and actuate the piezo at this frequency.
- Scan the region of interest at 500 x 500 pixels. Simultaneously with the microscopy image now also the amplitude and the phase of the oscillations were recorded at each pixel by the digital dual phase lock-in amplifier. The latter is automatically configured according to the actuating frequency.
- Reconstruct the deflection of the sample at each point

(a) Amplitude spectrum of the mirror



(b) Deflection images of vibrational modes

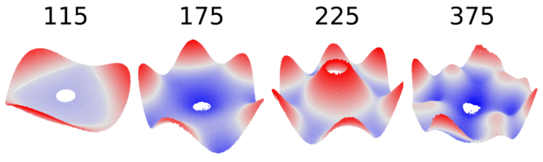
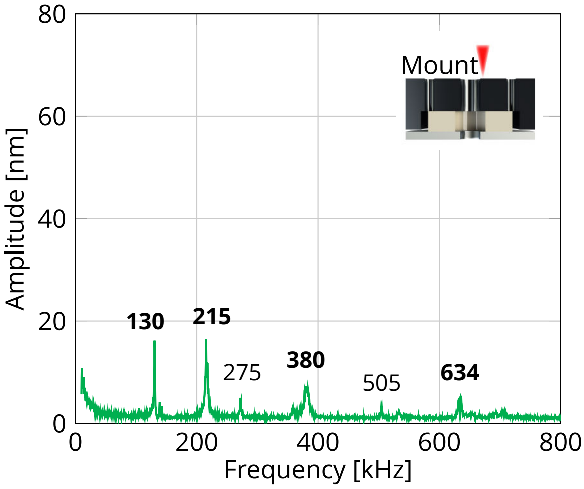


Figure 2. ***(a)*** *Frequency response of the polished titanium mirror, shown in the inset.* ***(b)*** *Deflection images of some resonant modes shown in (a). The amplitudes are normalized.*

(a) Amplitude spectrum of the mount



(b) Deflection images of vibrational modes

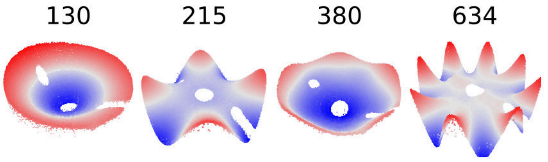


Figure 3. ***(a)*** *Frequency response of the titanium mount, shown in the inset.* ***(b)*** *Deflection images of some resonant modes shown in (a). The amplitudes are normalized.*

of the oscillation cycle by using the standard **PICO**SCAN VIEW software. Basically, for each pixel the deflection d is calculated from the measured amplitude A and phase θ according to $d = A \cdot \cos(\theta)$.

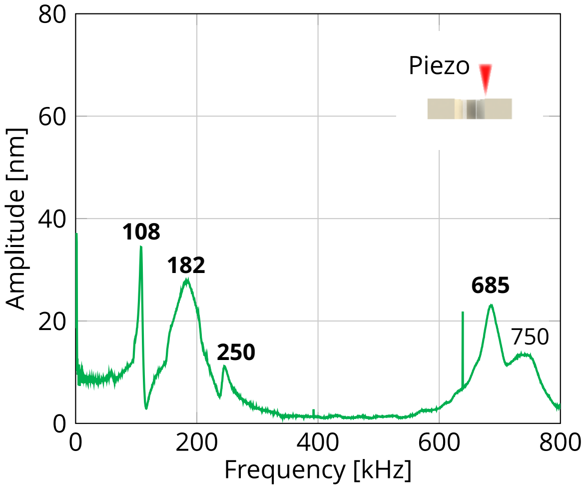
3. RESULTS

Due to the geometries and the contact boundary conditions, the vibrational modes cannot easily be described by mechanical models. To avoid confusion, they are defined by their resonant frequency rather than the number and kind of nodal lines present.

Investigation of top surface of the mirror: The local vibrations in Figure 2a reveals numerous resonance peaks from which many occur at lower frequencies than the stated resonance frequency of the ring piezo. To unfold the origin of these peaks the piezo was actuated accordingly. Figure 2b shows the acquired vibrational modes. The latter gain in complexities while the frequency of excitation increases.

Investigation of bottom surface of the mount: The local vibrations in Figure 3a uncovers multiple resonance peaks that largely differ from the one of the mirror. Indeed, the peak amplitudes are in general 3.5 times smaller and they appear narrower. Exciting the mount induced the vibrational modes displayed in Figure 3b. The vibrational discrepancies between the mirror and the mount more likely arise because of the respective geometries: the mirror is simply a flat pierced reflective cylinder while the mount has a more complex shape and is heavier. Furthermore, to mimic the behavior of the complete ultra-fast actuated

(a) Amplitude spectrum of the piezo



(b) Deflection images of vibrational modes

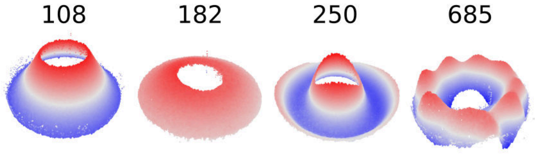


Figure 4. ***(a)*** *Frequency response of the mechanically decoupled piezo, shown in the inset.* ***(b)*** *Deflection images of few resonant modes shown in (a). The amplitudes are normalized.*

mirror, the lateral wall of the mount was mechanically constrained which reduced the possible traveling range of the system.

Investigation of the piezoelectric ring: In order to further dissect the origin of the resonance modes measured either on the mirror or on the mount, we assessed the dynamics of the bare piezo that was mechanically decoupled from stage, see methods. The frequency response of the ring chip is shown in Figure 4a. This spectrum is much smoother than the one of the other parts of the actuators and displays only few wide resonances peaks. Among them, none can be found in the spectrum of neither the mirror nor the mount. This suggests that the metal housing alters completely the general behavior of the piezo ring. The modes are also less complex, Figure 4b.

4. CONCLUSION

SmarAct's **PICO**SCAN Vibrometer was used to characterize the frequency response of an ultra-fast actuated mirror. The measurements of the vibrations at different location of the assembly allowed to define the influence of the housing on the dynamic behavior of the actuated mirror. Understanding the correlations between the resonance peaks and their vibrational modes helps to further optimize and control the design of actuators.

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