Comparison of force and moment behavior of bimorph actuator

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Summary
This paper deals with an actuator based on piezoelectric bimorphs developed at CTU for applications of ASAC on thin structures. The actuator takes the form of two pairs of bimorphs connected separately, so that the actuator can act in both moment and force configurations simultaneously. The ASAC system using this actuator was tested on a simple structure in the form of a steel strip fixed at both ends. The behavior of the actuator was compared with theoretical assumptions including efficiency of the actuator as a function of the position and power input. A good agreement has been demonstrated between the model results and the measurement.

PACS no. 43.38.Fx, 43.40.Vn

1. Introduction

Active control of radiation from a vibrating structure trough control of its vibrations is commonly called active structural acoustic control (ASAC). One of the tasks for researchers and engineers in this field is findig the appropriate actuators for ASAC applications. Their construction can be based on "classical" electrodynamic construction or piezo-stacks. The main construction challenge is to design an actuator with sufficient force or moment but with reasonable weight and supply voltage.

A few years ago, a light-weight line moment actuator based on one or more couples of bimorphs operating as a seesaw was designed [2]. Its function was tested on various simple structures (see e.g. [3]) and later it was modified to act as a force actuation as well [4].

The combined force-moment acutator has been tested on a simple structure to provide resonable data describing its behavior in the both force and moment configuration. Results from this testing are presented in this paper.

2. Modeled and measured results

For testing of behavior of the bimorph actuator, a simple structure base on a rectangular steel strip with dimensions of 30×6 cm and thickness of 0.4 mm fixed on both short sides was used. Assuming bending waves in the strip, its vibrations are described by the following equation

$$\frac{EI}{\rho S}\frac{\partial^4\eta}{\partial x^4} + \frac{\partial^2\eta}{\partial t^2} = 0 \tag{1}$$

where ρ is the density of the steel, E is the Young modulus, and $I = \frac{1}{12}bh^3$ is the moment of inertia with respect to the cross-section of the plate S. Using boundary conditions for strip (beam) fixed on both ends in the form

$$\left.\begin{aligned}\eta &= 0\\ \frac{\partial\eta}{\partial x} &= 0\end{aligned}\right\} \quad \text{for} \quad x = \pm\frac{1}{2} \tag{2}$$

we can calculate eigenfrequencies of the strip [5]. The first three frequencies for the selected dimension and material ($\rho = 7850\,\mathrm{kg}\cdot\mathrm{m}^{-3}$ and $E = 2.1\cdot 10^{11}\,\mathrm{Pa}$) of the strip are: 23.4 Hz, 64.5 Hz and 126.5 Hz. For modeling and testing of the bimorph, the third mode of 126.5 Hz was selected.

When the strip is excited by a force or moment, the wave equation (1) will contain a corresponding forcing function on its righ hand side. For both simulation and experiment we used a point force in the middle of the stripe representing primary excitation.

The radiated sound field was evaluated by means of sound pressure at the error microphone position, which was selected 0.5 m above the center of the strip. Sound pressure at the microphone position was calculated by means of numerical evaluation of the Reyleighs integral. The actuator was excited by the optimal magnitude of the signal, i.e. it corresponds to excitation at the first antinode for the force configuration and at the first (end) node for the moment configuration of the actuator. The phase was optimized

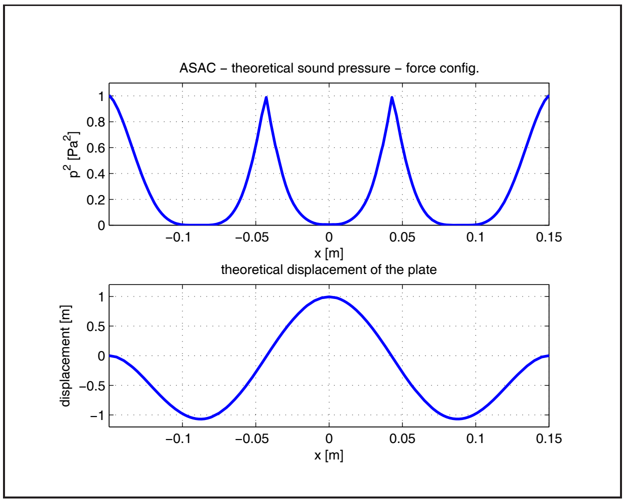

Figure 1. Normalized sound pressure at the microphone position for the force actuator.

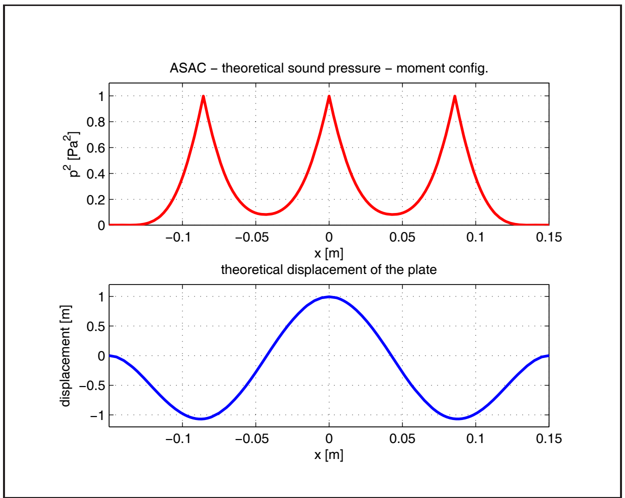

Figure 2. Normalized sound pressure at the microphone position for the moment actuator.

for every position of the actuator. The simulated normalized sound pressure at microphone position for the force configuration of the actuator is presented in Figure 1. Similarly, the result of simulation for moment configuration is in Figure 2. The shape of the third mode of the strip is below the normalized pressure for illustration.

In the second part of the actuator testing, we measure sound pressure levels at the microphone position similarly to the simulation. The steel stip was fixed to a sufficiently large chipboard baffle. Meassurements were performed with the actuator fixed successively at 19 points as can be seen in Figure 3. In the same figure, measured shape of selected mode is seen; this measurement was performed without bimorph actuator, so the real shape slightly differ from the depicted one.

The measured sound pressure level at the microphone position as a function of actuator position is shown in Figure 4. The actuator power input was constant for all positions and both configurations. The blue curve corresponds to the force configuration and the red curve to the moment configuration.

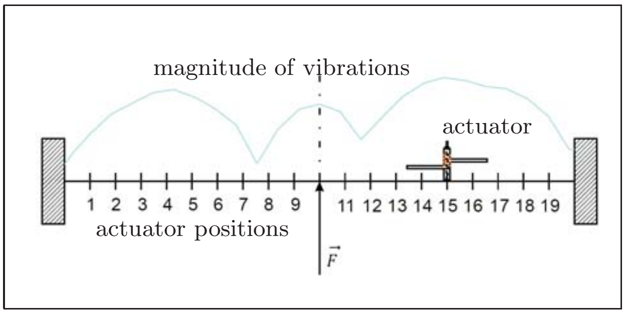

Figure 3. Measurement set-up with excitation force and positions of actuator.

In Figure 5, the required actuator input voltage for maximal attenuation as a function of actuator position for both force (blue) and moment (red) configuration is presented, showing the expected fact that the actuator in moment configuration has the lowest efficiency at antinodes of the strip, whereas the force actuator has the lowest efficiency at the ends (nodes).

3. Conclusions

The paper demonstrates the application of the force-moment actuator for ASAC on a simple structure. The possible efficiency of the actuator was modeled and measured. From the presented results, it can be seen that a good agreement of the model with the theory was achieved.

From the theoretical considerations it is clear that the actuator in moment configuration has to be fixed close to the nodal lines, while on the contrary the force actuator has to be fixed around antinodes. As the positions of the antinodes are less sharp then the nodal lines, the positioning of the force actuator is less sensitive to the exact location.

As follows from the presented measurements, moment actuation is from the energetic point of view advantageous only at the edges of the plate.

Combining moment and force excitation into one actuator is the subject of current research.

Acknowledgement

This project has been supported by the CTU research project SGS13/193/OHK3/3T/13 Monitoring and modeling methods in acoustics.

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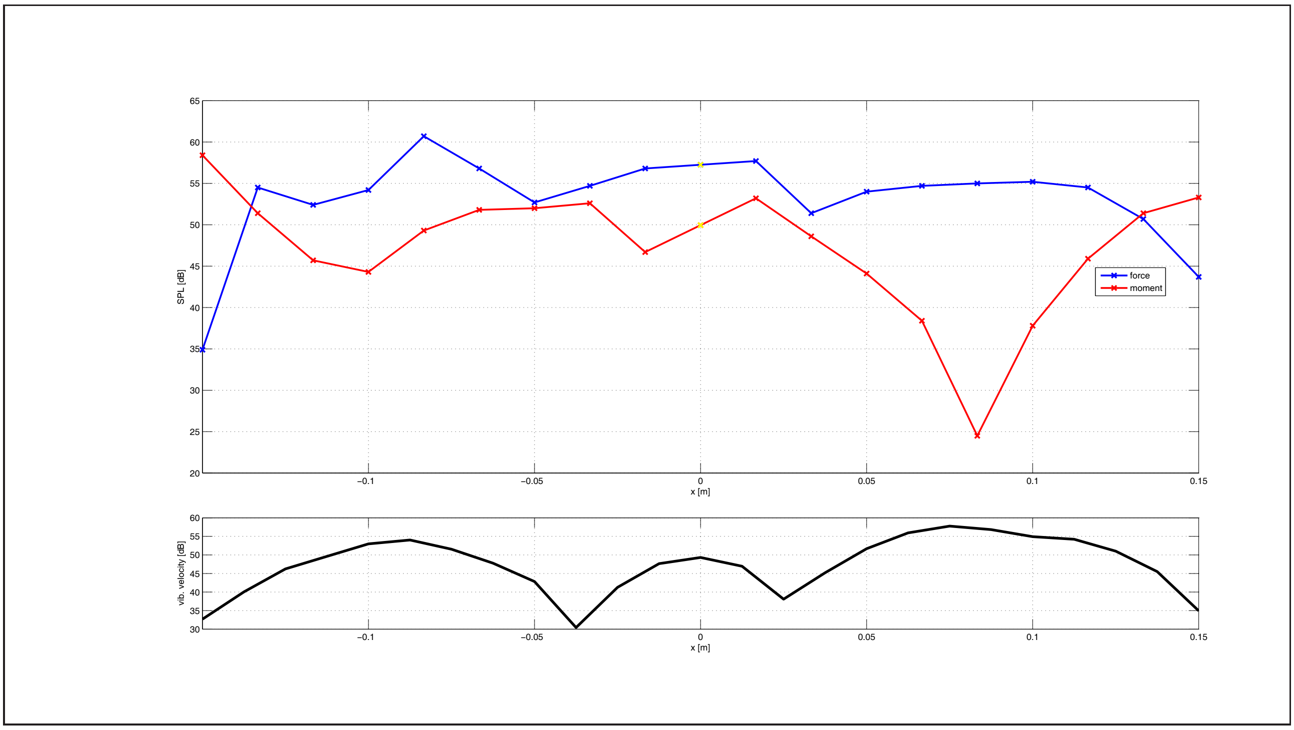

Figure 4. Sound pressure level generated by the actuator under the constant excitation.

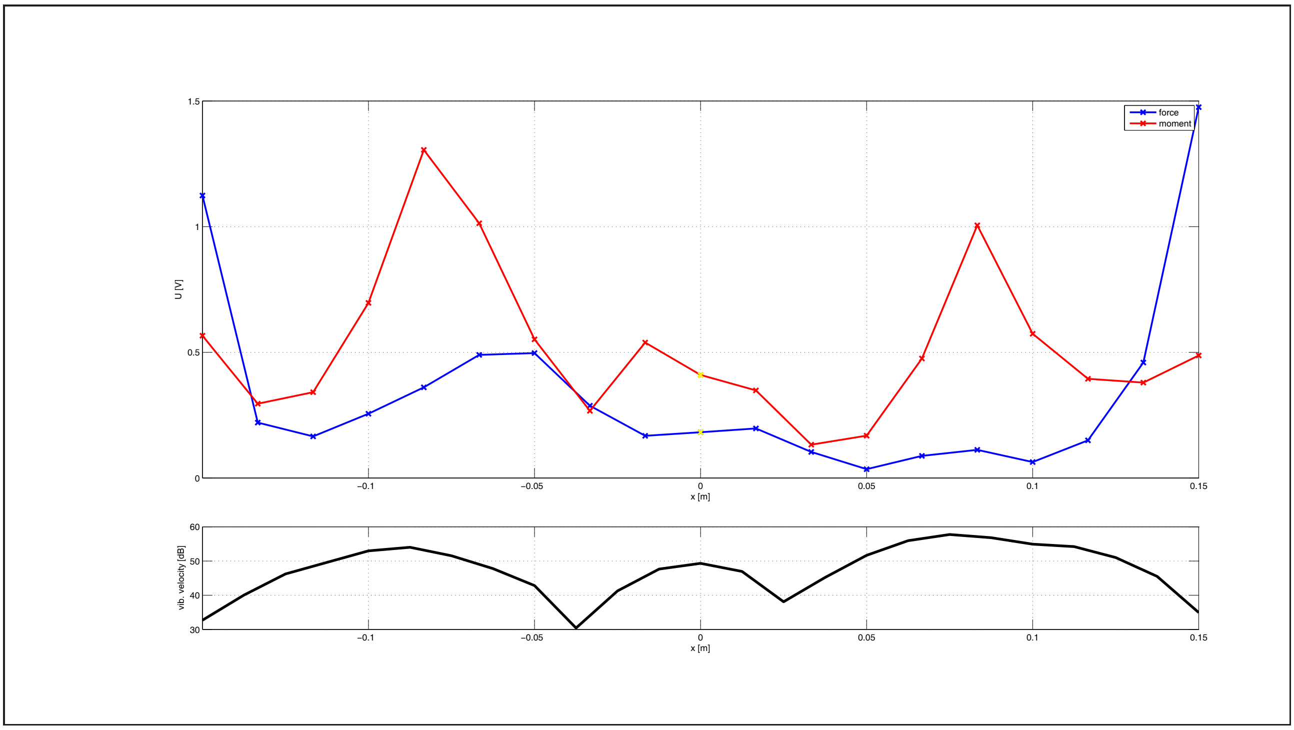

Figure 5. Required power input for the maximal attenuation.

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