Reduced order modelling with Deep Learning methods of the steady-state response in MEMS

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Abstract. Micro-Electro-Mechanical-Systems (MEMS) are nowadays essential components in high-end technology applications e.g., resonators and gyroscopes. The ever-growing demand for increasing performances requires performing nonlinear dynamic simulations that are mostly unaffordable using standard full-order simulation techniques such as the Finite Element Method (FEM). Data-Driven Reduced Order Models (ROMs) provide an appealing alternative starting from data and without acting intrusively in the reduction procedure itself. In this contribution, we propose a technique that, by exploiting deep-learning autoencoders and harmonic decomposition, generates efficient and accurate ROMs for the steady-state regime in resonating MEMS.

Introduction

In order to meet the design requirements related to sensitivity and output signal strength, MEMS are usually actuated at resonance, in near-vacuum conditions with large quality factors. Consequently, these devices experience geometric nonlinearities induced by the large transformations. Predicting the steady-state response of such systems through standard full-order approaches like the FEM creates a computational bottleneck due to the large dimensionality of the resulting nonlinear system and the high-quality factors. Such difficulties can be overcome through dedicated approaches like e.g., the Harmonic Balance (HB) method, as proposed in [1]. Nevertheless, for large systems, non-standard computing facilities are needed. ROMs provide a solution to these problems since, through a dimensionality reduction, the system can be modelled with a limited number of variables i.e., latent variables, that underlie the dynamics. Data-driven, and in particular Deep Learning methods, provide a non-intrusive solution to build ROMs. In this contribution, taking inspiration from many applications in the literature [2, 3, 4], we use a deep-learning autoencoder to build a low-dimensional representation of the dynamics. Furthermore, we enrich these approaches by modelling the steady-state regime through its harmonic components, retained up to the desired order. The latent space, once built, is used to query new unseen solutions through interpolation.

Results and discussion

We consider a MEMS micromirror fabricated by ST Microelectronics, illustrated in Fig.1. The mirror is assumed to be made of isotropic polysilicon, with density $\rho = 2330\,\mathrm{Kg/m^3}$, Young modulus $E = 167\,\mathrm{GPa}$ and Poisson coefficient $\nu = 0.22$. The torsional mode is the third one and has a frequency of 29271 Hz, we assume a quality factor $Q = 1000$. The results from the proposed ROM are compared with Full Order Model (FOM) solutions in Fig. 1 considering different forcing levels. The ROM highlights an excellent accuracy considering that the reduced subspace created with the autoencoder consists of a single latent variable, i.e. equivalent to a one degree of freedom oscillator.

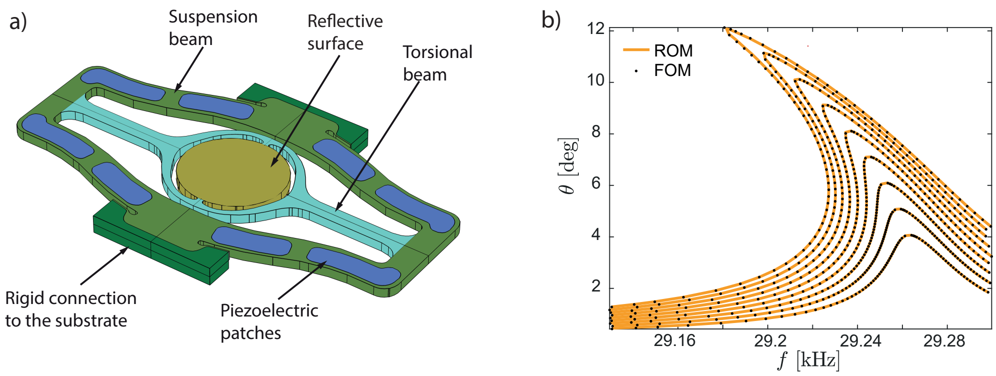

Figure 1: Fig.a) Scheme of the MEMS micromirror. Fig. b) comparison between the FOM solution and the proposed ROM

References

[1] Opreni, A., et al. (2021) Analysis of the nonlinear response of piezo-micromirrors with the harmonic balance method *Actuators, MDPI* **10**:2

[2] Fresca, S., et al. (2022) POD-DL-ROM: enhancing deep learning-based reduced order models for nonlinear parametrized PDEs by proper orthogonal decomposition *Comp. Meth. in Appl. Mech. and Eng.* **388**:114181

[3] Champion, K., et al. (2019) Data-driven discovery of coordinates and governing equations *Proc. of the National Academy of Sciences* **116.45**: 22445-22451

[4] Fresca, S., et al. (2022) Deep learning-based reduced order models for the real-time simulation of the nonlinear dynamics of microstructures *Int. J. for Num. Meth. in Eng.* **123.20**:4749-4777