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Improving response of a MEMS capacitive microphone filtering shock noise

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ABSTRACT

This paper deals with the effects of mechanical shock loads on the stability and dynamic response of a MEMS circular capacitive microphone. As results demonstrate, mechanical shock loads affect the dynamic response and the stability region of the capacitive microphone. The results show that the mechanical shock loads can induce considerable noise in the response of the microphone. Therefore, noise filtering is an important issue to eliminate the output response distortions. To achieve this aim we propose a structure for the capacitive microphone with an electrical circuit in order to eliminate the shock noise. In addition the effect of a delay in shock application is also studied, and it is illustrated that a delay in shock application plays an important role in the stability of the capacitive microphone.

1. Introduction

A microphone is a transducer that converts acoustic energy into electrical energy. The microphones are widely employed in many applications such as cell phones, personal computers, car navigation systems, home-use robots, voice communications devices, hearing-aids, surveillance and military aims, and noise and vibration control [1–3]. Generally microphones can be divided into three types: dynamic microphones, condenser microphones and optical microphones [1].

A condenser or capacitive microphone couples acoustical, mechanical and electrical domains. To date because of high sensitivity and low noise levels capacitive microphones are the most common type of silicon microphone [2]. A condenser microphone conceptually consists of a thin vibrating diaphragm and a rigid ground plate that are separated by a small air gap. The relative movement of the diaphragm to the ground plate is solely due to the applied acoustic pressure on the diaphragm, so that the ground plate has no movement as the reference. It means that the ground plate should be thick enough not to move [4]. Capacitive microphones usually need a dc biasing voltage to obtain an ac output if the sensing capacitance changes due to the sound pressure [5].

Traditional microphones, such as Brüel and Kjær condenser microphones, offer excellent performance, but are costly and currently not suitable for miniaturization [6]. Microelectromechanical systems (MEMS) technology has been rapidly growing since its beginning in the 1980s. With the development of MEMS technology, hundreds or thousands of devices can be fabricated together on a single silicon wafer. This leads to the production of MEMS microphones that can approach the performance of traditional microphones with lower cost and smaller size [6].

Currently, commercialization of MEMS devices is a major focus for engineers. One of the most critical issues affecting the commercialization of MEMS devices such as MEMS microphones is their reliability under mechanical shock and impact. MEMS capacitive microphones can be exposed to shock during fabrication, deployment, and operation. Since mechanical shock can induce considerable dynamic loads, it can cause some problems such as chipping, cracking and fracture in the structures [7]. Severe motions and dropping on hard surfaces can induce highly dynamic loads in the MEMS capacitive microphones, which may lead to mechanical and/or electrical failure. Mechanical shock loads can cause capacitive microphones diaphragm to hit the stationary ground plate underneath it, causing stiction [8] and short circuit problems [9] and hence it's failure. Since the majority of microstructures are fabricated of silicon or polysilicon, they are very tough against bending stresses induced from shock acceleration. Therefore, failure through stiction and electric short circuits due to contacts between movable and stationary electrodes is more possible than the failure through direct breaking due to contact stresses [7].

A shock can be defined as a force applied suddenly over a short period of time relative to the natural period of the structure [10]. A shock pulse can be characterized by its maximum value,

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duration and shape. The structural response to a mechanical shock must be measured and characterized during the engineering development of MEMS devices so that they can survive all environments during their service lifetime. Response of the MEMS structures under mechanical shock loads has been investigated by several researchers and it is currently an increasing area of interest of intense research because of importance of the reliability factor in MEMS devices.

Beliveau et al. [11] experimentally studied the response of commercial accelerometers to shock loads and reported some unexpected results. Brown et al. [12] subjected commercial accelerometers and pressure sensors to high-*g* tests. They could not receive suitable results and suggested that an improved dynamic model of MEMS devices under shock load is needed. Lim et al. [13] studied the effects of shock on a MEMS actuator using the FE software ANSYS. Wagner et al. [14] studied the response of a MEMS accelerometer to a shock load induced by a drop test. They used the linear beam theory for rough estimations, and FE analysis to calculate the stress history of the device during impact. Fan and Shaw [15] simulated the response of a comb-drive accelerometer subjected to severe dynamic shock loads in all directions using an FE model in ABAQUS software with full nonlinear and contact stress capability. They remarked that this problem requires a highly nonlinear transient dynamic analysis, which is computationally very expensive. Li and Shemansky [16] studied the motion of MEMS accelerometers during drop tests. They used a single-degree-of-freedom (SDOF) model and a continuous system beam model to account for the flexibility of the structures and calculated their maximum deflection. Srikar and Senturia [17] modeled microstructures using an undamped SDOF model attached to an accelerating base. Yee et al. [18] and Millet et al. [19] analyzed the behavior of fixed–fixed microbeams under shock loads. They represented the shock load as a static point load applied at the middle of the beam. They used a linear beam model for small deflection cases and Raleigh–Ritz technique for large-deflection cases and indicated that their solution is not numerically accurate even for small deflections. Tas et al. [8] identified electrostatic and accelerated forces during shock as two possible cases for the contact in the microstructures during the operation of the MEMS devices, which leads to stiction problem and failure of devices, but they did not study the simultaneous effect of electrostatic forces and mechanical shock loadings. Coster et al. [20] modeled the behavior of the RF MEMS switch actuated by an electrostatic force subjected to shock using a SDOF model. Younis et al. [7] presented modeling, simulation and characterization for the dynamic response of clamped–clamped microbeams under mechanical shock by applying a Galerkin-based reduced-order model. Botta and Cerria [21] studied a plate under impulse loads and obtained the correlated shock response spectrum. Ibrahim and Younis [22] presented a theoretical and experimental investigation of the response of electrostatically actuated parallel-plate resonators when subjected to mechanical shock using a single-degree-of-freedom system.

A circular capacitive MEMS microphone consisting of a thin circular diaphragm suspended over a ground plate is a sensitive device, which can be exposed to mechanical shocks through its wide ranges of applications. From the aforementioned review, effects of mechanical shock loads on the stability and dynamic response of circular capacitive microphones are not investigated in previous works sufficiently. Therefore in this paper, the stability of circular capacitive microphones under mechanical shock loads with various durations, amplitudes and different delays is studied. Moreover, it is shown that the shock can induce unsought noises in the response of the circular microphone; therefore, a structure is proposed to filter unsought shock noises in the microphone response. The proposed structure consists of two capacitors and an accompanying electrical circuit to separate sound pressure signals from the shock ones in the microphone output. The paper uses Galerkin-based reduced-order model and the time history approach to solve the equations.

2. Model description and mathematical modeling

The proposed microphone consists of mechanical and electrical parts. The mechanical part consists of two circular capacitors next to each other. One is the desired MEMS capacitive microphone , which is exposed to sound waves that experiences sound pressure waves and mechanical shock loads simultaneously. The other one is protected from sound waves and is only exposed to mechanical shock loads. In order to prevent increase of the size of the MEMS microphone, due to the low value of the initial gap and the low value of the diaphragm thickness, the microphone diaphragm can be located on the protected one. The circular capacitors have similar material and geometrical properties and each of them can be modeled as two circular micro-plates with a voltage between them as shown in Fig. 1. The upper plate is a thin deformable elastic circular plate with thickness $h(-h/2 \le z \le h/2)$, radius $R(-R \le r \le R)$, and is isotropic, with Young's modulus E and Poisson's ratio ν, and which is held fixed along its boundary and acts as a diaphragm. The lower plate must be thick enough as it has no movement as the reference. The space between these plates is filled with a dielectric substance like air. The diaphragm vibrates when is struck by the sound waves or shock loads. Diaphragm vibration changes the charge of the capacitors. The cylindrical coordinate system (r,θ,z) with the origin located at the center point of the plate is utilized to study the transversal vibration of the thin circular diaphragm as shown in Fig. 1.

In order to filter the shock signals in the microphone an ordinary electric circuit is given in Fig. 2. In this circuit the

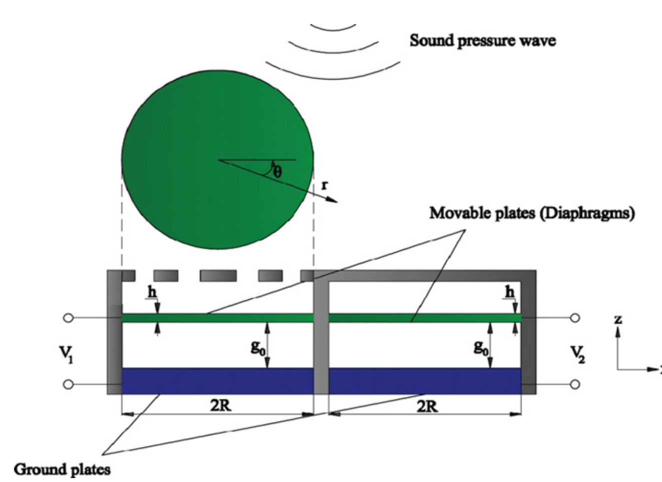

Fig. 1. Schematic view of the novel capacitive microphone.

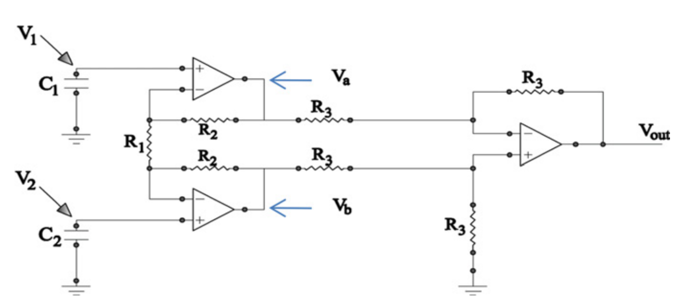

Fig. 2. Schematic view of the electric circuit used to filter the shock noise.