Sensors and Actuators A 212 (2014) 93–101

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

A novel MEMS omnidirectional inertial switch with flexible electrodes

Xi Zhanwen [a,*], Zhang Ping [a], Nie Weirong [a], Du Liqun [b], Cao Yun [a]

[a] School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, People's Republic of China
[b] School of Mechanical Engineering, Dalian University of Technology, Dalian 116024, People's Republic of China

ARTICLE INFO

Article history:
Received 24 October 2013
Received in revised form 17 February 2014
Accepted 24 February 2014
Available online 14 March 2014

Keywords:
Omnidirectional inertial switch
MEMS
Flexible electrode
Enhanced contact effect

ABSTRACT

A novel MEMS omnidirectional inertial switch was designed, simulated and fabricated. The switch is composed of three main parts, the proof mass, the axial flexible electrode and four radial flexible electrodes. It introduces the flexible electrodes to form a dual mass–spring system. The switch has omnidirectional sensitivities in a half sphere. When any acceleration, over the threshold value in radial or/and axial direction, acts to the switch, the switch will turn on. Also, the switch has the enhanced contact effect. Dynamic simulation results based on FEM confirm that the contact effect is improved by this new design compared to that of traditional inertial switch. The contact duration is prolonged under the shock loading, and the bouncing effect is alleviated. The switch has a 6-layer structure, which is manufactured based on non-silicon surface micromachining technology. The tests have been done and the results coincide with that of the simulation.

1. Introduction

MEMS inertial switches, also known as to shock sensors or threshold accelerometers, have great potential to be widely used in toys, accessories, automotive, military weapons and industrial applications. That is due to their smaller size, lower cost, less power consumption, more functionality and better performance than conventional mechanical ones. Furthermore, the inertial switches have ability of avoiding electromagnetic interference in applications [1,2].

The MEMS omnidirectional inertial switch usually has a structure with a mass–spring system, where the proof mass served as the movable electrode and is suspended by surrounding springs [3] .There is also other structure with a proof mass suspended by central springs [4–6]. The schematic diagram of these conventional designs is shown in Fig. 1. In Fig. 1, when the switch responses to a shock acceleration, the movable electrode will contact with stationary electrode in rigid mode. The contact-bouncing effect would be inevitable and the switch-on time is transient (usually less than 10 μs)[7,8]. The poor contact-bouncing effect and the short switch-on time make it difficult for signal processing and weaken the reliability of the switch [9,10]. The movable contact point [1,7], squeeze film effect [1], the carbon nanotube (CNT)-contact pad [11], electrostatic force [12], have been adopted to the inertial micro-switches to prolong the contact duration and eliminate contact-bouncing effect, but these inertial switches were limited to a single axis of sensing.

The present work proposed a novel design of the MEMS omnidirectional inertial switch with four radial and an axial flexible electrodes shown in Fig. 2. By introducing this flexible contact mechanism, the switch forms a dual mass–spring system, which gives the improved switch characteristics such as omnidirectional sensitivities, reduced contact-bouncing effect and prolonged switch-on time.

2. The inertial switch design and simulation

2.1. Design and working principle

The structure of the omnidirectional inertial switch is illustrated in Fig. 3. It senses acceleration in hemisphere (both in-plane and out-of-plane) with the single proof mass. The proof mass thickness t is designed to be much larger than the spring thickness t_1 in order to minimize the area coverage while enabling the desired radial and axial direction sensitivity. Four radial flexible electrodes supported by spring are symmetrical around the proof mass. Each one has the gap of d_1 from the proof mass. The circle loop supported by an elastic cross beam is used as the axial flexible electrode. It has a distance of d_2 from the proof mass, which also helps to enhance the contact effect in axial direction. The use of flexible electrodes is to prolong the switch-on time and make the switch-on state more stable.

* Corresponding author. Tel.: +86 2584303068.
E-mail address: njniewr@hotmail.com (X. Zhanwen).

http://dx.doi.org/10.1016/j.sna.2014.02.035
0924-4247/

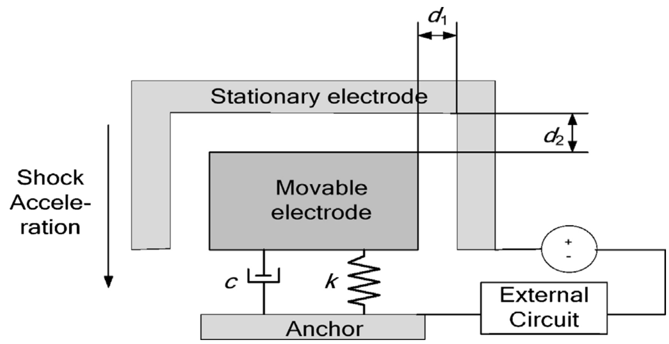

Fig. 1. A schematic diagram of conventional inertial switch.

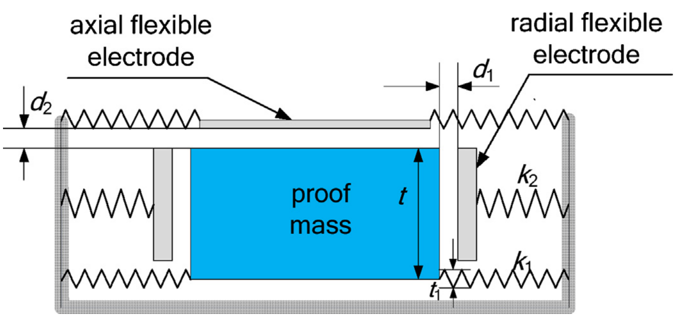

Fig. 2. A schematic diagram of the novel inertial switch.

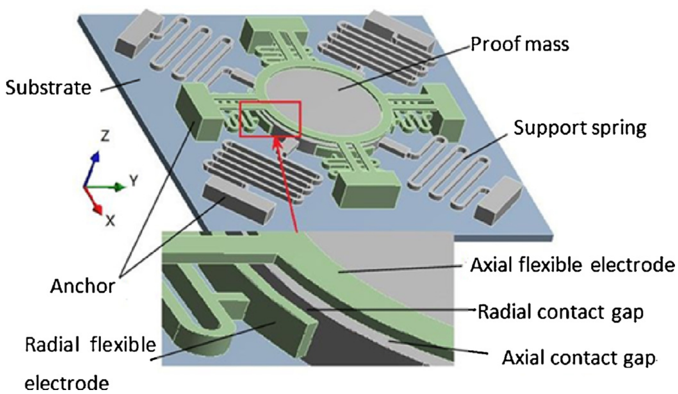

Fig. 3. Structural sketch map of the proposed inertial switch. (a) A conventional inertial MEMS switch with the fixed electrodes (b) A inertial MEMS switch with flexible electrodes.

Apart from the proof mass–spring system (m_1, k_1), the radial flexible electrodes are suspended by spring instead of being rigidly fixed on the substrate. The axial flexible electrode is supported by elastic cross beam. The radial and axial flexible electrodes have contact gap d_1 and d_2 from the proof mass, respectively. For example, as for an acceleration acting along the +Z axis, the working principle is demonstrated by the dynamic process and corresponding switch state, as shown in Fig. 4. Fig. 4(a) shows the action process of a conventional inertial MEMS switch with the fixed electrode. Fig. 4(b) explains the action process of the novel inertial MEMS switch with flexible electrodes. In Fig. 4(b), (1) The proof mass moves towards one of flexible electrodes due to the acceleration. (2) When the acceleration exceeds the threshold value, the displacement reaches d_2, the proof mass contacts the flexible electrode and the switch is turned on. (3) The proof mass keeps moving on with the flexible electrode, therefore the switch-on state is held on for a longer time. (4) After the disappearance of the acceleration, the proof mass and the flexible electrode rebound, the switch is turned off, until the proof mass is separated from the flexible electrode. (5) Finally, the proof mass and the flexible electrode restore to the equilibrium position after all the energy is dissipated by free vibration.

As for an acceleration acting along other directions in hemisphere, the proof mass moves towards the flexible electrodes in radial and/or axial direction, the switch state is similar to aforementioned cases. The inertial switch has radial and axial flexible electrodes, and it is able to provide identifiable direction information according to the identified electrode position.

When acceleration is applied on the switch in the sensitive directions, the proof mass will be subjected to the inertial acceleration $a(t)$ in the opposite direction. Take radial direction motion as example, the responding motion can be expressed with the motion equation as:

$$m_1\ddot{x} + c\dot{x} + k_1 x + m_1 a(t) = 0 \quad (1)$$

where m_1 is the mass of the proof mass, x is the displacement in radial direction, c presents the damping coefficient, k_1 is the system stiffness and $a(t)$ is the applied acceleration component in radial direction and is a function of time t. The acceleration $a(t)$ applied to the switch in practical work is similar to a half-sine pulse with amplitude a_0 and duration t_0 (about 1 ms). To simplify the solving process, c is neglected [9]. By solving Eq. (1), we have the displacement $x(t)$ of the proof mass.

$$x(t) = \frac{a_0}{\omega_n^2 - \omega_0^2}\left(\sin\omega_0 t - \frac{\omega_0}{\omega_n}\sin\omega_n t\right) \quad (2)$$

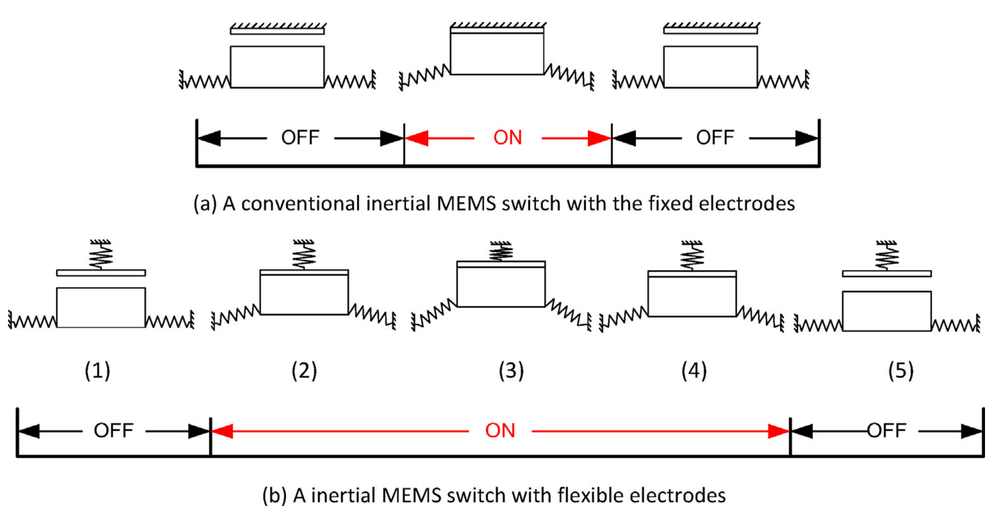

Fig. 4. Comparison of the dynamic process and switch state between (a) and (b).