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Influence of applied acceleration loads on contact time and threshold in an inertial microswitch with flexible contact-enhanced structure

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ABSTRACT

An inertial microswitch with flexible contact-enhanced structure to prolong contact time has been designed and fabricated by surface micromachining technology. The flexible structure is an *L*-shaped compliant cantilever beam, which can realize elastic deformation during contact process when the movable electrode impacts to the stationary electrode. The influence of applied acceleration loads on contact time and threshold was analyzed, simulated and evaluated. The analysis results indicate that the stiffness of inertial system, amplitude and pulse width of acceleration loads are important influence factors for the contact time: the contact time will be increased along with the increase of acceleration amplitude and the decrease of inertial system stiffness. The broadening of pulse width of acceleration loads will result in a greater value of threshold acceleration and contact time. The simulated results demonstrate that the dynamic properties of designed inertial micro-switch are in agreement with the analytical ones. The fabricated microswitch has been tested by dropping hammer system, the test results indicate that the threshold acceleration is about 110*g* and the corresponding contact time is about 42 μs when the pulse width is about 1.7 ms. Meanwhile, the contact time increases with the broadening of pulse width. Finally, the fabricated inertial microswitch device has been also tested under applied half-sine wave acceleration with different amplitudes and pulse widths. It is indicated that the contact time does not increase after reaching to a maximum (75 μs under 259*g* applied acceleration load). From the analysis in the present work, the influence of applied shock loads on contact time and threshold level in an inertial microswitch with flexible contact-enhanced structure is revealed. The conclusions reached in this study provide guidance for future research into the design and fabrication of inertial microswitches.

1. Introduction

Inertial microswitch based on Micro-electromechanical Systems (MEMS), as a typical kind of acceleration sensor controlled by threshold acceleration, is widely used in many industrial applications such as automobiles, toys and particularly the Internet of Things (IOT) system [1–3]. In the accelerometer trigger system, the control and decision element send out the triggering messages to executive components when the signal peak of acceleration exceeds the designed threshold-level, and then the trigger unit will carry out triggered actions. Compared with accelerometer, the inertial microswitch is both sensor and actuator, the movable electrode contacts the stationary electrode and the external circuit is triggered when the acceleration amplitude reach to the threshold. This kind of purely mechanical trigger is superior to accelerometer due to the electromagnetic interference resistance [3]. Furthermore, the accelerometer always contain a constant parasitic power draw even no acceleration and impact happening. The inertial microswitch is widely applied in some small-scale or long-lifetime system where the power supply is limited [4–7]. A serious of inertial microswitches with no parasitic power consumption had been proposed in our previous work [8–10].

The inertial microswitch is a kind of sensor which is driven by the applied acceleration, and the movable electrode contacts the stationary electrode when the applied acceleration amplitude exceeds its threshold. The contact time is a critical factor in some application environments, because the long contact time will decrease the difficulties of signal-processing while short contact time demands higher signal identification performance of external circuit. In this paper, an inertial microswitch with flexible contact-enhanced structure will be proposed and fabricated and the contact time will be also prolonged compared with the previous inertial microswitches. However, the contact time was influenced by the amplitude and pulse width of acceleration loads. In some

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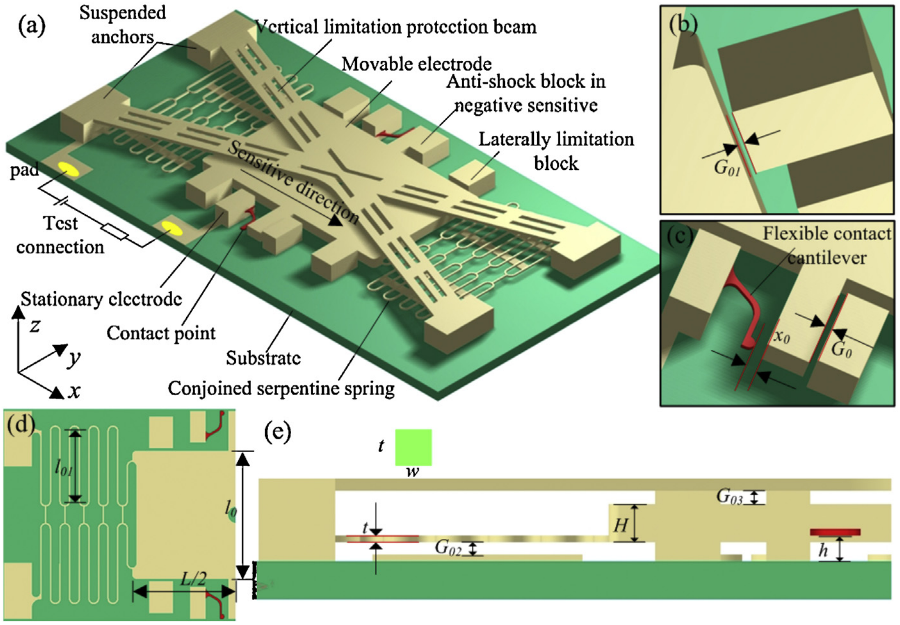

Fig. 1. The structure diagram of inertial micro-switch. (a) The 3D view of structure. (b) The gap between block and proof mass. (c) The enlarged view of contact point and anti-shock block. (d) The top view of one-half structure. (e) The side view of one-half structure.

applications it is required the threshold acceleration and contact time can be controlled accurately, where the microswitch must be designed and fabricated precisely. So the relationship between the contact time, threshold acceleration and the applied acceleration load will be analyzed and characterized in this paper. And the corresponding inertial microswitch device will be also fabricated and evaluated.

2. Structure design

The structure of inertial microswitch fabricated by multi-electroplating technology is designed, which mainly consists of three parts: the proof mass is suspended by two sets of conjoined serpentine springs as the movable electrode, two blocks locate beside proof mass as the stationary electrodes and the contacts point are suspended by the blocks, another six blocks and a cross beam with holes are used to restrain the movement of proof mass in the *y* and *z* directions. The movable electrode can move toward to the stationary electrode and touches the contact point when the acceleration amplitude reaches the designed threshold-level in sensitive direction (*y* direction). The designed whole structure is shown in Fig. 1.

The gap between the proof mass and the anti-shock block shown in Fig. 1(b) and (c) is set as 5 μm ($G_0 = G_{01} = 5$ μm). Compared with traditional inertial switch, the small gap between movable electrode and limit blocks could be obtained utilizing the unique advantage of micromachining process. The small gap could effectively weaken the rebound of proof mass when the inertial micro-switch was shocked, which avoids mistakenly triggering in non-sensitive directions. The cross-beam with holes above proof mass plays an implant role to protect the device in the vertical direction. The flexible contact cantilever is shown in Fig. 1(c), which can realize elastic deformation to prolong contact time when the proof mass contact with the contact point. Fig. 1(d) and (e) shows the top and side views of one half structure of the inertial microswitch.

3. The analysis and simulation

3.1. Theoretical analysis

Fig. 2 is the schematic diagram of dynamic response process of the designed inertial microswitch. The inertial microswitch is simplified into a double spring vibration system due to the cantilever beam can be considered as an elastic structure. The applied acceleration load is transformed to force by the spring-mass vibration structure and then it is transmitted to cantilever beam when the applied acceleration exceeds the designed threshold-level. Subsequently, the elastic deformation of the cantilever will occur under the force from spring-mass. The contact time will be determined by the amount of deformation because the proof mass touches the contact point during the whole contact process. The whole procedure can be described in Fig. 2, as follow:

Fig. 2(a) shows the initial state of inertial microswitch, the quality of proof mass is defined as m, k and k_1 are the elastic coefficients of the suspended spring and cantilever beam, respectively. The gap between proof mass and cantilever is defined as x_0. The proof mass will contact the cantilever when the acceleration a reaches to the designed threshold of the inertial switch, and then the microswitch will turn on, as shown in Fig. 2(b). The process shown in Fig. 2(b) would be considered as an ideal contact process, but this state is only an instantaneous dynamic process. So, overload acceleration is required for the inertial microswitch in order to keep "turn on" state usually. The cantilever beam deforming under the overload acceleration is shown in Fig. 2(c). The elastic deformation of the cantilever will result in prolonging the contact time. When the proof mass and cantilever reach to the maximal displacement, the equilibrium equation can be expressed as

$$F(t) = f_a(t) - f_k(t) = ma(t) - (kx_0 + kd + k_1 d) = 0 \quad (1)$$

where $f_a(t) = ma(t)$ and $f_k(t) = kx_0 + kd + k_1 d$, respectively, The cantilever and proof mass move in negative direction when $f_a(t) < f_k(t)$. The proof mass and cantilever will return to the state shown in Fig. 2(d) when the force $f_a(t) = kx_0$. Fig. 2(e) shows that the proof mass recovers to the original position under the spring force.