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Stress relaxation insensitive designs for metal compliant mechanism threshold accelerometers

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ABSTRACT

We present two designs for metal compliant mechanisms for use as threshold accelerometers which require zero external power. Both designs rely on long, thin flexures positioned orthogonally to a flat body. The first design involves cutting or stamping a thin spring-steel sheet and then bending elements to form the necessary thin flexors. The second design uses precut spring-steel flexure elements mounted into a mold which is then filled with molten tin to form a bimetallic device. Accelerations necessary to switch the devices between bistable states were measured using a centrifuge. Both designs showed very little variation in threshold acceleration due to stress relaxation over a period of several weeks. Relatively large variations in threshold acceleration were observed for devices of the same design, most likely due to variations in the angle of the flexor elements relative to the main body of the devices.

1. Introduction

Previous work has demonstrated the idea of using a fully-compliant bistable mechanism as a threshold accelerometer [1,2]. Such a device is especially interesting as a sensor requiring zero power which can be left in place over long periods. Potential applications would include package shipping in which these types of sensors could indicate harmful shocks or drops. Sensors could also be placed on vehicles, buildings, or bridges [3–5] to monitor impacts or seismic activity. Reports have been made on a variety of low power or zero power accelerometer designs, often involving MEMS structures and monitoring circuitry built on VLSI chips [6–9]. While a macroscopic bistable design cannot be readily fabricated on a silicon substrate, it can be integrated with RFID sensors for remote, zero power sensing of acceleration events [10]. While a number of zero power mechanical structures exist and are commercially available [11, 12] there remains a desire to pursue lower cost alternatives which can be easily adapted to automated readout systems.

The previous and present bistable mechanism designs use four compliant flexible members with two stable positions. The mechanism's central shuttle is meant to attach to an object and measure its acceleration. In these types of mechanisms, as the flexible members are acted upon by an external force, elastic energy can be stored and then released as kinetic motion. The device's outer frame serves as a proof mass which causes a force on the compliant members when under acceleration. If acceleration goes beyond a threshold, the proof mass moves between two possible stable positions, in effect recording a “threshold” event. The basic design and a force–displacement diagram are shown in Fig. 1.

Compliant mechanism threshold accelerometers have been made from sheets of Delrin and ABS plastic and formed through laser cutting [1]. While plastic offers low manufacturing costs and these devices did display bistable switching behavior, they were susceptible to changes in switching threshold over time due to stress relaxation of their flexor elements [13]. In fact, an average increase of 54% in the threshold acceleration was measured after leaving the devices in the stressed state for 72 h [13]. This kind of drift is very undesirable for a zero power sensor meant to be used over long periods.

To address the problem of plastic relaxation, metal threshold accelerometers have been made from sheets of spring steel with designs cut using wire Electrical Discharge Machining (EDM) [14]. Flexor elements were formed by bending thin strips of the spring steel perpendicular to the outer frame. These devices exhibited long term stability with regard to threshold acceleration, but were susceptible to “out of plane” movement during switching. Bracketing elements had to be added to the frames, which induced friction and made thresholds unpredictable from device to device.

This paper introduces two new metal threshold accelerometer designs, both of which have long term threshold stability and do not

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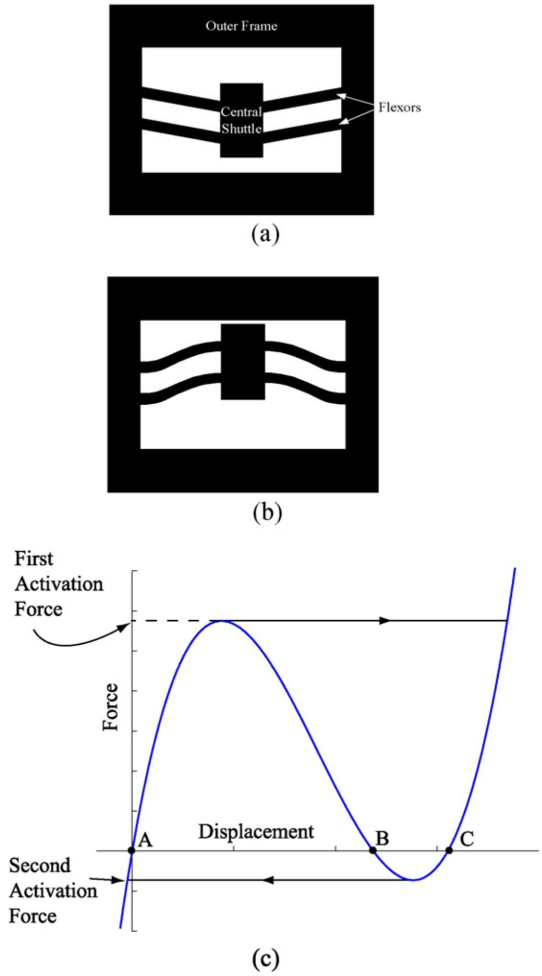

Fig. 1. (a) Compliant bistable mechanism design with four flexor elements in the first stable position, corresponding to point A on the force vs. displacement diagram in (c). (b) Compliant bistable mechanism in the second stable position, corresponding to point C on the diagram in (c). Point B is the unstable position.

require bracketing elements to keep switch motion in a single plane. The first design builds from the earlier work involving cutting spring steel and then bending to form flexor elements. The second design uses metal molding to form a switch with spring steel flexors and a tin frame. Fabrication details for both designs are provided along with a description of how acceleration thresholds were tested. Data demonstrating low variation to stress relaxation for both designs is shown.

2. Fabrication

2.1. Cut and bend design

Our compliant mechanism designs require flexors with small in-plane widths compared to their out-of-plane thicknesses. To achieve this in our "cut and bend design" a sheet of 0.004 in. (~100 μm) spring steel was cut using wire EDM into the shape shown in Fig. 2a. The cut piece was then placed in a specially designed fixture (Fig. 2b) which allowed for the thin flexor elements to be bent down perpendicular to the plane of the main body of the device. A small-diameter drill bit (#60–1.02 mm diameter) was placed in the fixture to guide the bend, avoiding excessive stress during bending. The design is amenable to fabrication by stamping. This design differs from the earlier version of the "cut and bend" devices in that previous versions included a thin segment of the flexor that was intended to be plastically deformed in torsion. The thin torsion segments resulted in very small out-of-plane stiffness, requiring the placement of guides to prevent out-of-plane motion [15]. The guides induced friction during switch motion. In contrast, the "cut and bend" designs presented here have no rubbing surfaces during motion.

After bending the flexor elements, 2.5 mm thick plastic frames were glued to the outer frame of the devices to add support and weight. Fig. 3 shows photos of the completed accelerometers in both stable positions. The added plastic frames are below the spring steel frames and not visible in these pictures.

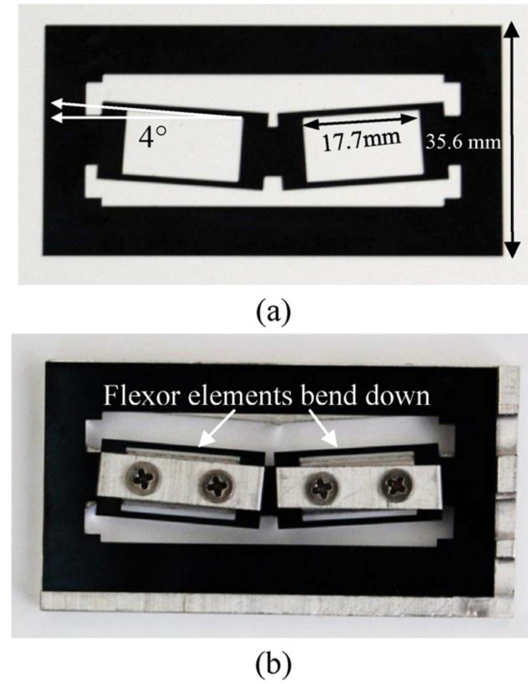

Fig. 2. (a) Top view photograph of the spring steel "cut and bend design" accelerometer after being cut using wire EDM. (b) The cut spring steel positioned in custom fixture used for bending flexor elements perpendicular to the outside frame.

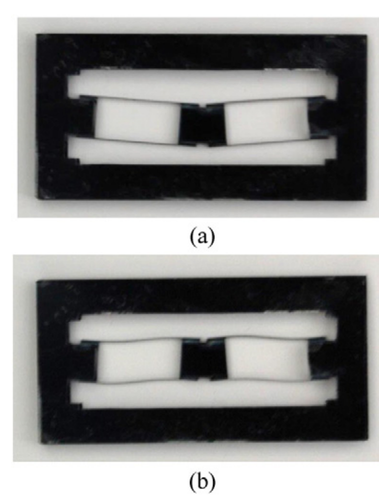

Fig. 3. (a) "Cut and bend" design in the first stable position. (b) The same device in the second stable position with the flexor elements deformed. A plastic frame has been attached to the bottom of the device's outer frame to provide stability and extra weight.