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Tucker et al.

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(54) **SINGLE-AXIS ACCELEROMETER**

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G01P 15/09 (2006.01)
H01L 41/16 (2006.01)

(52) **U.S. Cl.**
CPC ***G01P 15/09*** (2013.01); ***H01L 41/16*** (2013.01)

(58) **Field of Classification Search**
CPC G01P 15/09
USPC 73/514.34
See application file for complete search history.

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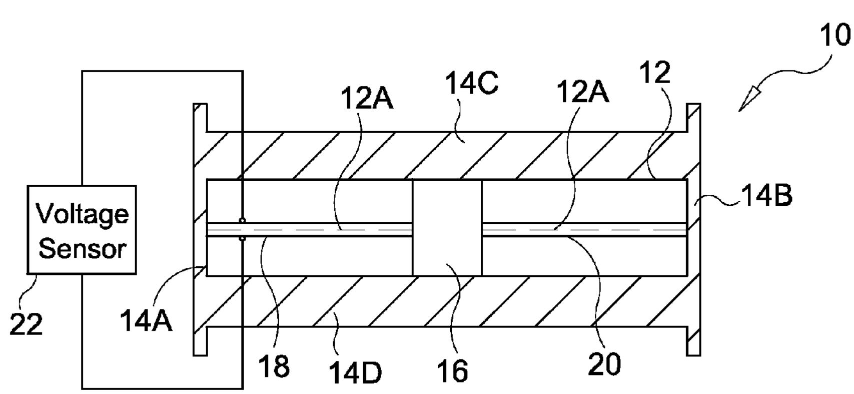
(57) **ABSTRACT**

A single-axis accelerometer includes a housing defining a sleeve. An object/mass is disposed in the sleeve for sliding movement therein in a direction aligned with the sleeve's longitudinal axis. A first piezoelectric strip, attached to a first side of the object and to the housing, is longitudinally aligned with the sleeve's longitudinal axis. The first piezoelectric strip includes a first strip of a piezoelectric material with carbon nanotubes substantially aligned along a length thereof. A second piezoelectric strip, attached to a second side of the object and to the housing, is longitudinally aligned with the sleeve's longitudinal axis. The second piezoelectric strip includes a second strip of the piezoelectric material with carbon nanotubes substantially aligned along a length thereof. A voltage sensor is electrically coupled to at least one of the first and second piezoelectric strips.

15 Claims, 1 Drawing Sheet



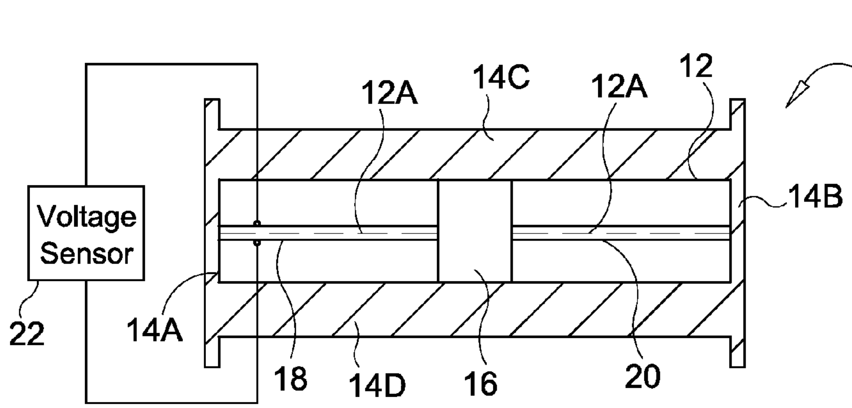


FIG. 1

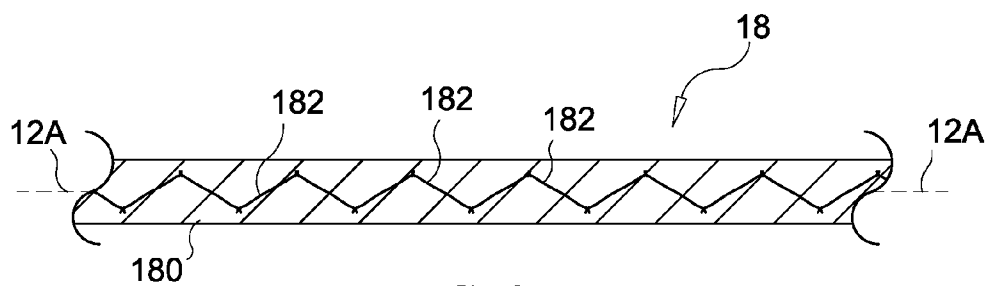


FIG. 2

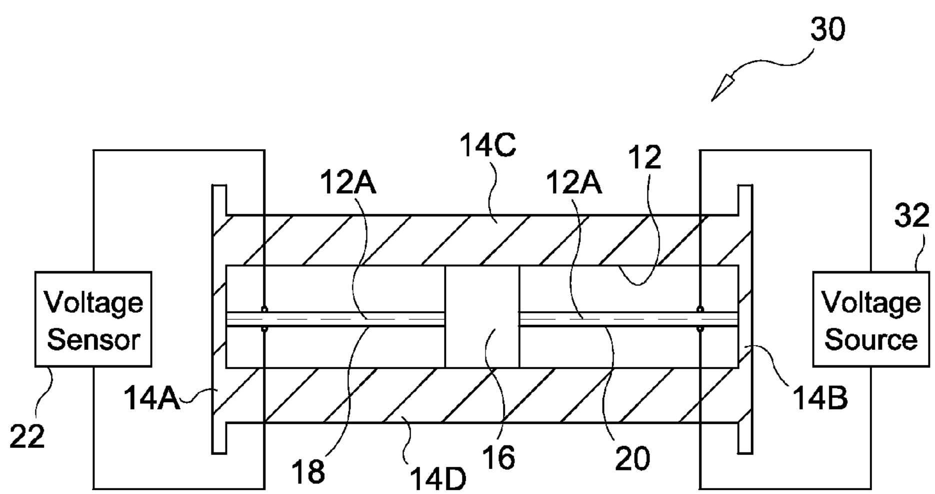


FIG. 3

SINGLE-AXIS ACCELEROMETER

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to accelerometers. More specifically, the invention is a single-axis accelerometer.

2. Description of the Related Art

Conventional accelerometers generally utilize a pendulum's movement or a piezoelectric material to sense acceleration. Pendulum-based accelerometers are relatively large and expensive. Piezoelectric-based accelerometers are traditionally made from ceramic materials such as barium titanate ($BaTiO_3$) or lead titanate (PZT). However, these materials are inherently brittle, have a tendency to be noisy, have difficulty sensing low frequencies, and are subject to static charge build-up that affects polarization. Still further, piezoelectric materials used in "micro electro-mechanical machine system" (MEMS) accelerometers behave as a spring system that generates noise requiring compensation.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an accelerometer.

Another object of the present invention is to provide a carbon nanotube-piezoelectric-based accelerometer that avoids the drawbacks generally associated therewith.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a single-axis accelerometer includes a housing defining a sleeve having a longitudinal axis. An object having a mass is disposed in the sleeve for sliding movement therein in a direction aligned with the sleeve's longitudinal axis. A first piezoelectric strip is attached to a first side of the object and to the housing. The first piezoelectric strip is longitudinally aligned with the sleeve's longitudinal axis. The first piezoelectric strip includes a first strip of a piezoelectric material with carbon nanotubes substantially aligned along a length of the first strip. A second piezoelectric strip is attached to a second side of the object and to the housing. The second side of the object opposes its first side. The second piezoelectric strip is longitudinally aligned with the sleeve's longitudinal axis. The second piezoelectric strip includes a second strip of the piezoelectric material with carbon nanotubes substantially aligned along a length of the second strip. A voltage sensor is electrically coupled to at least one of the first piezoelectric strip and second piezoelectric strip.

BRIEF DESCRIPTION OF THE DRAWING(S)

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. **1** is a side schematic view of a single-axis accelerometer in accordance with an embodiment of the present invention;

FIG. **2** is a cross-sectional view of a piezoelectric strip used in the accelerometer in accordance with an embodiment of the present invention; and

FIG. **3** is a side schematic view of a single-axis accelerometer employing active damping in accordance with another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring now to the drawings and more particularly to FIG. **1**, a single-axis accelerometer in accordance with an embodiment of the present invention is shown and is referenced generally by numeral **10**. Accelerometer **10** is a piezoelectric-based accelerometer that can be oriented in any of a variety of ways to measure acceleration along a particular direction (e.g., acceleration due to gravity, some applied motive force, etc.). Accordingly, it is to be understood that the orientation of the accelerometer shown in the figures is not a limitation of the present invention.

Accelerometer **10** includes a housing that defines a sleeve **12** having a longitudinal axis indicated by dashed line **12**A. In the illustrated embodiment, the housing includes opposing end walls **14**A and **14**B, and opposing sidewalls **14**C and **14**D such that sleeve **12** is tubular in nature. For example, side walls **14**C and **14**D could be partial or half cylinders so that sleeve **12** is cylindrical in cross-section.

Disposed in sleeve **12** for sliding movement therein is an object **16** having a mass. More specifically, sleeve **12** constrains sliding movement of object **16** to a single dimension or axis aligned with longitudinal axis **12**A. Such sliding movement in either direction (e.g., left or right in the illustrated orientation of accelerometer **10**) is indicative of acceleration in the opposite direction. That is, acceleration is to the right when object **16** slides to the left, and acceleration is to the left when object **16** slides to the right. Accordingly, the surfaces of sleeve **12** and object **16** that will come into contact with one another should be configured/constructed to minimize friction in ways well understood in the art.

Object **16** is positioned (e.g., centered) in sleeve **12** by piezoelectric strips **18** and **20** disposed in the air space in sleeve **12** on either side of object **16**. More specifically, each piezoelectric strip **18** and **20** is coupled to object **16** and to a portion of the housing defining sleeve **12**. In the illustrated embodiment, the ends of piezoelectric strip **18** are affixed to end wall **14**A and one side of object **16**. The ends of piezoelectric strip **20** are affixed to the opposing side of object **16** and end wall **14**B. Strips **18** and **20** are aligned along the longitudinal axis **12**A of sleeve **12**.

A voltage sensor **22** (e.g., meter) is electrically coupled to one of piezoelectric strips **18** and **20**. For purpose of the present invention, voltage sensor **22** is coupled to piezoelectric strip **18** across the thickness thereof. In this way, when accelerometer **10** experiences acceleration along a direction aligned with the sleeve's longitudinal axis **12**A, voltage sensor **22** will sense positive/negative voltage changes induced in piezoelectric strip **18** due to either compression of strip **18** (i.e., acceleration to the right) or tension in strip **18** (i.e., acceleration to the left). A second voltage sensor (not shown) could be electrically coupled to piezoelectric strip **20** without departing from the present invention.

In the present invention, each of piezoelectric strips **18** and **20** is configured in the same fashion and includes a matrix of piezoelectric material with carbon nanotubes

(CNTs) therein. More specifically and with reference to FIG. **2**, a portion of piezoelectric strip **18** is shown in cross-section where the piezoelectric matrix is referenced by numeral **180** and the CNTs are referenced by numeral **182**. CNTs **182** are substantially aligned along the length of strip **18** such that they are also substantially aligned along the length of the sleeve's longitudinal axis **12**A when strip **18** is included in accelerometer **10**. For purposes of the present invention, CNTs **182** can occupy approximately 30 to approximately 50 volume percent of strip **18**. The piezoelectric matrix **180** can be a flexible piezoelectric material such as polyvinylidene fluoride (P(VDF)) or polyvinylidene trifluoroethylene (P(VDF-TrFE)). To enhance the piezoelectric effect produced by piezoelectric strip **18**, additives such as magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$) can be added to piezoelectric matrix **180**.

A variety of techniques can be used to fabricate piezoelectric strips **18** and **20**. For example, piezoelectric matrix **180** could be sprayed onto CNTs **182** as the CNTs were being drawn and then wound onto a spool. The drawing of CNTs **182** will cause their substantial alignment as the matrix material is sprayed thereon. To facilitate spraying, the piezoelectric matrix material can be mixed into a solvent (e.g., DMF) that will ultimately evaporate leaving just the piezoelectric matrix material **180** encapsulating the substantially aligned CNTs **182**. The desired lengths for strips **18** and **20** can then be cut.

Another accelerometer embodiment of the present invention is illustrated in FIG. **3** and is referenced generally by numeral **30**. The elements of accelerometer **30** that are the same as accelerometer **10** are referenced with the same numerals and will not be described again herein. Accelerometer **30** is actively damped by including a voltage source **32** electrically coupled to piezoelectric strip **20**. Voltage source **32** is coupled across the thickness of strip **20**. In general, voltage source **32** applies a voltage to strip **20** to actively dampen oscillations in strip **20** when accelerometer **30** experiences acceleration along longitudinal axis **12**A. Accordingly, accelerometer **30** is effectively a spring-damper system that can dampen oscillations that are inherent in piezoelectric materials in order to improve the response of accelerometer **30**. Since piezoelectric strip **20** also includes CNTs therein, minimal voltage is needed to make piezoelectric strip **20** act as a damper. This will allow accelerometer **30** to be miniaturized and utilize low voltage levels typically available from conventional microcontrollers.

The advantages of the present invention are numerous. A simple single-axis accelerometer avoids the size constraints of pendulum-based accelerometers and avoids the drawbacks of conventional piezoelectric-based accelerometers. The piezoelectric strips are flexible and less noisy than ceramic materials, but are more responsive due to the inclusion of CNTs. The accelerometer can be actively damped with a low-level voltage to improve response.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A single-axis accelerometer, comprising:

a housing defining a sleeve having a longitudinal axis;

an object having a mass disposed in said sleeve for sliding movement therein in a direction aligned with said longitudinal axis;

a first piezoelectric strip attached to a first side of said object and attached to said housing, said first piezoelectric strip longitudinally aligned with said longitudinal axis, said first piezoelectric strip including a first strip of a piezoelectric material with carbon nanotubes substantially aligned along a length of said first strip;

a second piezoelectric strip attached to a second side of said object and attached to said housing, said second side opposing said first side, said second piezoelectric strip longitudinally aligned with said longitudinal axis, said second piezoelectric strip including a second strip of said piezoelectric material with carbon nanotubes substantially aligned along a length of said second strip; and

a voltage sensor electrically coupled to at least one of said first piezoelectric strip and said second piezoelectric strip.

2. A single-axis accelerometer as in claim **1**, wherein said piezoelectric material is selected from the group consisting of polyvinilydene fluoride (P(VDF)) and polyvinilydene trifluoroethylene (P(VDF-TrFE)).

3. A single-axis accelerometer as in claim **1**, further comprising additives mixed in said piezoelectric material, said additives being selected from the group consisting of magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$).

4. A single-axis accelerometer as in claim **2**, further comprising additives mixed in said piezoelectric material, said additives being selected from the group consisting of magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$).

5. A single-axis accelerometer as in claim **1**, further comprising a voltage source coupled to one of said first piezoelectric strip and said second piezoelectric strip.

6. A single-axis accelerometer, comprising:

a housing defining a sleeve having a longitudinal axis;

an object having a mass disposed in and constrained by said sleeve for sliding movement therein only in a direction aligned with said longitudinal axis;

a first piezoelectric strip attached to a first side of said object and attached to said housing, said first piezoelectric strip longitudinally aligned with said longitudinal axis, said first piezoelectric strip including a first strip of a piezoelectric material with carbon nanotubes embedded in and substantially aligned along a length of said first strip;

a second piezoelectric strip attached to a second side of said object and attached to said housing, said second side opposing said first side, said second piezoelectric strip longitudinally aligned with said longitudinal axis, said second piezoelectric strip including a second strip of said piezoelectric material with carbon nanotubes embedded in and substantially aligned along a length of said second strip; and

a voltage sensor electrically coupled to one of said first piezoelectric strip and said second piezoelectric strip.

7. A single-axis accelerometer as in claim **6**, wherein said piezoelectric material is selected from the group consisting of polyvinilydene fluoride (P(VDF)) and polyvinilydene trifluoroethylene (P(VDF-TrFE)).

8. A single-axis accelerometer as in claim **6**, further comprising additives mixed in said piezoelectric material, said additives being selected from the group consisting of magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$).

9. A single-axis accelerometer as in claim **7**, further comprising additives mixed in said piezoelectric material, said additives being selected from the group consisting of magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$).

10. A single-axis accelerometer as in claim **6**, further comprising a voltage source coupled to one of said first piezoelectric strip and said second piezoelectric strip.

11. A single-axis accelerometer, comprising:

a housing defining a sleeve having a longitudinal axis;

an object having a mass disposed in and constrained by said sleeve for sliding movement therein only in a direction aligned with said longitudinal axis, wherein air spaces are defined in said sleeve on opposing sides of said object;

a first piezoelectric strip attached to a first of said opposing sides of said object and attached to said housing, said first piezoelectric strip disposed in one of said air spaces and longitudinally aligned with said longitudinal axis, said first piezoelectric strip including a first strip of a piezoelectric material with carbon nanotubes embedded in and substantially aligned along a length of said first strip, said carbon nanotubes occupying approximately 30-50 volume percent of said first piezoelectric strip;

a second piezoelectric strip attached to a second of said opposing sides of said object and attached to said housing, said second piezoelectric strip disposed in another of said air spaces and longitudinally aligned with said longitudinal axis, said second piezoelectric strip including a second strip of said piezoelectric material with carbon nanotubes embedded in and substantially aligned along a length of said second strip, said carbon nanotubes occupying approximately 30-50 volume percent of said second piezoelectric strip; and

a voltage sensor electrically coupled to one of said first piezoelectric strip and said second piezoelectric strip.

12. A single-axis accelerometer as in claim **11**, wherein said piezoelectric material is selected from the group consisting of polyvinilydene fluoride (P(VDF)) and polyvinilydene trifluoroethylene (P(VDF-TrFE)).

13. A single-axis accelerometer as in claim **11**, further comprising additives mixed in said piezoelectric material, said additives being selected from the group consisting of magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$).

14. A single-axis accelerometer as in claim **12**, further comprising additives mixed in said piezoelectric material, said additives being selected from the group consisting of magnesium niobate-lead titanate (PMN-PT), lead zirconium titanate (PZT), and barium titanate ($BaTiO_3$).

15. A single-axis accelerometer as in claim **11**, further comprising a voltage source coupled to another of said first piezoelectric strip and said second piezoelectric strip.

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