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THINLINE TOWED ARRAY TENSION SENSOR

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein was made in the performance of official duties by employees of the U.S. Department of the Navy and may be manufactured, used, or licensed by or for the Government of the United States for any governmental purpose without payment of any royalties thereon.

CROSS REFERENCE TO OTHER APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

1) Field of the Invention

[0003] The present invention relates generally to thin-line towed arrays, and more particularly to an apparatus that measures tension in a thin-line towed array.

2) Description of Related Art

[0004] Naval vessels use thin-line towed-array systems that are up to several miles in length and contain a network of delicate telemetry and sensor components. Each module of the thin-line array includes an outer sheath or hose that contains hydrophones and supporting electronics.

[0005] Referring to prior art of **FIG. 1**, each module **100** includes an Internal Strength Member (ISM) **102**. The ISM **102** comprises ropes **104** that terminate on a clevis **106** at each end of the module **100**. The ISM **102** is contained within an array hose **108**. The module **100** elongates under tension. The tension can be measured with a tension sensor.

[0006] Accordingly, substantive improvements in tension sensors are needed for towed arrays. However, developing a sensor for the thinline, towed array may be challenging because of the small diameter and other integration requirements.

SUMMARY OF THE INVENTION

[0007] The present invention uses a planar tab that facilitates a tension sensor function as well as the construction of the strength package in the towed array where the tension sensor is installed.

[0008] The tension sensor includes the planar tab having a first side and a second side, a first end section and a second end section, and an aperture or hole through each of the end sections. A first strain gage is positioned on the first side of the tab. The strain gage has a tension grid aligned with a longitudinal axis of the tab and a cross-tension grid perpendicular to the tension grid. A second strain gage attaches to the second side of the tab. The second strain gage has a

tension grid aligned with the longitudinal axis of the tab and a cross-tension grid perpendicular to the tension grid.

[0009] The first strain gage and the second strain gage are wired in a Wheatstone bridge in which the tension grid and the cross-tension grid of the first strain gage form one side of the Wheatstone bridge and the tension grid and the cross-tension grid of the second strain gage form another side of the Wheatstone bridge. Voltage change across the Wheatstone bridge is measured as a function of strain on the tab.

[0010] An array hose is formed as part of the thin-line towed array with an internal strength member inside the hose. A clevis defines a termination point of a module of the array. The hose and the strength member connect to the clevis. The internal strength member includes a plurality of ropes that terminate on the clevis. Typically, there is a clevis or termination point on both ends of the towed array. The tension sensors attach to a portion of the plurality of ropes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] 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:

[0012] **FIG. 1** is a prior art and cross-sectional view of an end of a towed array module;

[0013] **FIG. 2** depicts a tension tab with a mounted first strain gage in accordance with the present invention;

[0014] **FIG. 3** depicts a cross-section of a tension tab taken along reference line **3-3** of **FIG. 2**;

[0015] **FIG. 4** depicts a tension tab with a mounted second strain gage in accordance with the present invention with the view taken along reference line **4-4** of **FIG. 3**;

[0016] **FIG. 5** depicts a Wheatstone bridge in accordance with the present invention;

[0017] **FIG. 6** depicts a sensor node with four strain gages where elongation is linearly proportional to tension in the range of interest; and

[0018] **FIG. 7** is a flow chart of the method of use of the tension sensor in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] Strain may be defined as deformation experienced by a body resulting from an application of force. According to an inventive apparatus described herein, a tension sensor fits within a small diameter array hose such as an array hose **108**.

That is, the outer diameter and rigid length of the tension sensor must be less than the maximum that the array hose **108** can accommodate. Larger diameters must have proportionally smaller rigid lengths.

[0020] A strain gage measures the amount of strain on a given object by converting a dimension change to a change in electrical resistance. Referring to **FIG. 2**, a tension sensor **110** of the present invention includes a planar tab **112** having a first side **114** and a second side **116**. The tab **112** may be made of titanium.

[0021] The planar tab **112** has a first end section **118** and a second end section **120**. Apertures or holes **122** are provided through each of the end sections **118**, **120**. A first strain gage **124** attaches to the first side **114** of the tab **112**. The strain gage **124** has a tension grid **126** aligned with a longitudinal axis of the tab **112** and a cross-tension grid **128** perpendicular to the tension grid **126**.

[0022] Referring to **FIG. 3** and **FIG. 4**, a second strain gage **130** attaches to the second side **116** of the planar tab **112**. The second strain gage **130** has a tension grid **132** aligned to the longitudinal axis of the tab **112** and a cross-tension grid **134** perpendicular to the tension grid **132**. In use, some of the ropes **104** from the ISM **102** are spliced into the apertures or holes **122** at each end section **118**, **120** of the tab **112**. The strain gages

124, 130 bond to the sides **114, 116** of a middle section of the tab **112**. Tension on the ISM **102** is transmitted into the tab **112** and measured by the strain gages **124, 130**.

[0023] The cross-sectional area, "A" of the tab **112** is calculated in Equation **(1)** from the definition of Young's Modulus, where "F" is the maximum design tension, "E" is Young's Modulus, and "ϵ" is the strain when the maximum design tension is applied.

$$A = \frac{F}{E\epsilon} \quad \textbf{(1)}$$

[0024] In this example, T-rosette strain gages are used. The cross sectional area of the tab **112**, A = w * t, is set by choosing ϵ to be 2,000 $\mu\epsilon$ - per the specifications of the strain gage manufacturer. And F is set to match the breaking strength of the rope **104** that the tab **112** interrupts (1,200 pounds in this situation). Accordingly, the rope **104** will break before the tab **112** exceeds the region of elastic deformation for the rope. The stress concentration at the apertures **122** on each side **114, 116** determine the required thickness. In the described examples, Titanium Ti6Al4V was used to keep thickness to a minimum while preserving strength, but unalloyed titanium, aluminum, or aluminum alloys could also meet strength requirements and fit in the towed array module **100**.

[0025] As shown in **FIG. 5,** the first strain gage **124** and the second strain gage **130** (depicted in the preceding figures) are wired in a Wheatstone bridge **136** in which the tension grid **126** and the cross-tension grid **128** of the first strain gage form one side of the Wheatstone bridge and the tension grid **132** and the cross-tension grid **134** of the second strain gage **130** form another side of the Wheatstone bridge.

[0026] The tension-induced strain proportionally changes the voltage E_0. "E" is the excitation voltage supplied to the Wheatstone bridge **136.** The resistance of the tension grid **126, 132** parallel to the tension axis (the longitudinal axis of the tab **112**) varies linearly with strain (ϵ) along the tension axis and the resistance of the cross-tension grid **128, 134** perpendicular to the tension axis varies linearly with perpendicular strain $(-v\epsilon)$ where v is Poisson's ratio. The cross-tension grid **128, 134** leverages Poisson's effect to prevent thermal expansion and contraction in the tab **112** from affecting E_0. In another embodiment, mounting cages can be used on each side of the tab **112** to prevent bending from affecting E_0.

[0027] The response of the Wheatstone bridge **136** is calculated by Equation **(2)**

$$R = \frac{E_0}{E} = \frac{G\epsilon(1+v)\times 10^{-3}}{2 + G\epsilon(1-v)\times 10^{-6}} \qquad \textbf{(2)}$$

where "*R*" is the bridge output in mV/V, "*G*" is the gage factor provided by the manufacturer, and "*v*" is Poisson's ratio of the material on which the gage is mounted, 0.342 for Ti6Al4V in this case. Equation **(2)** can be used with Young's modulus to calculate responses.

[0028] The tension sensor **110** interfaces with the telemetry of the thinline towed array. A sensor node relays a voltage measurement up the data stream of the towed array. Two voltage inputs are used by the sensor node and the node provides the voltage excitation for use in the resistive tension sensing element. As shown in **FIG. 6**; the sensor node uses two full-bridge inputs; thus, four tabs **112** can be wired in two pairs of two tabs.

[0029] Each of the four tabs **112** has the strain gages **124, 130** arranged in a full-bridge output. The strain gages **124, 130** are not shown for clarity in **FIG. 6** but are shown and described for **FIG. 2** and **FIG. 4**. Since the sensor node has two full-bridge inputs, the four tabs **112** are wired in two pairs of two tabs. The strain gages **124, 130** measure strain by changing electrical resistance in response to elongation. The strain gages **124, 130** are mounted to the four tabs **112** where elongation is linearly proportional to tension in the range of interest. The resistance change is measured by the towed array telemetry as a voltage change across the strain gages **124, 130.**

[0030] The tabs **112** are spliced into four of the ropes **104** in the ISM **102**. For accuracy and stability, a tab **112** could be spliced into each of the ropes **104**, but the sensor node in the towed array only uses two inputs. Data from the four tabs **112** is averaged in pairs in order to provide two outputs for input to the sensor node.

[0031] **FIG. 7** is a flow chart illustrating the assembly and use of the invention. According to the invention, real time tension can be measured in a thin-line towed array. A tension sensor is integrated into the Internal Strength Member (ISM) of the Forward Interface Module (FIM) at the front of the towed array and measures the tension due to drag along the towed array.

[0032] At step **138**, a first strain gage is bonded to a first side of a tab with the tension grid of the first strain gage aligned with the longitudinal axis of the tab. At step **140**, a second strain gage is bonded to a second side of the tab with the tension grid of the second strain gage aligned with the longitudinal axis of the tab. At step **142**, the first strain gage and the second strain gage are wired in a Wheatstone bridge in which the tension grid and cross-tension grid of the first strain gage form one side of the Wheatstone bridge and the tension grid and cross-tension grid of the second strain gage form another side of the Wheatstone bridge.

[0033] At step **144**, a first end of the tab is connected to an end of a module of the thin-line towed array. At step **146**, a second end of the tab connects to the internal strength member inside the module of the thin-line towed array. At step **148**, voltage change across the Wheatstone bridge is measured as a function of strain on the tab.

[0034] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

THINLINE TOWED ARRAY TENSION SENSOR

ABSTRACT OF DISCLOSURE

A tension sensor includes a planar tab having a first and second side, first and second end sections and an aperture through each of the end sections. A first strain gage is attached to the first side of the tab. The first strain gage has a tension grid aligned to a longitudinal axis of the tab and a cross-tension grid perpendicular to the tension grid. A second strain gage is attached to the second side of the tab. The second strain gage has a tension grid aligned to the longitudinal axis of the tab and a cross-tension grid perpendicular to the tension grid. The first strain gage and second strain gage are wired in a Wheatstone bridge in which the tension grid and the cross-tension grid of the first strain gage form one side and the tension grid and the cross-tension grid of the second strain gage form another side.

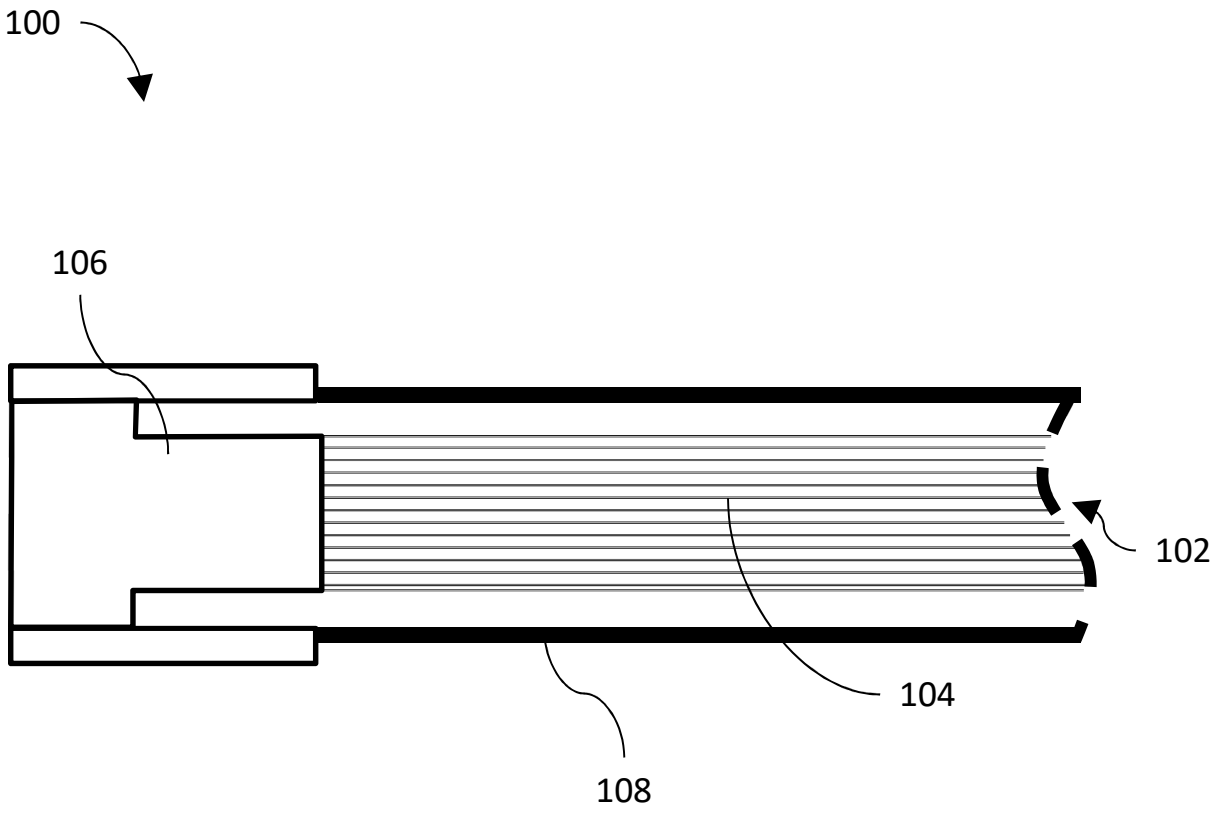

FIG. 1

-PRIOR ART-

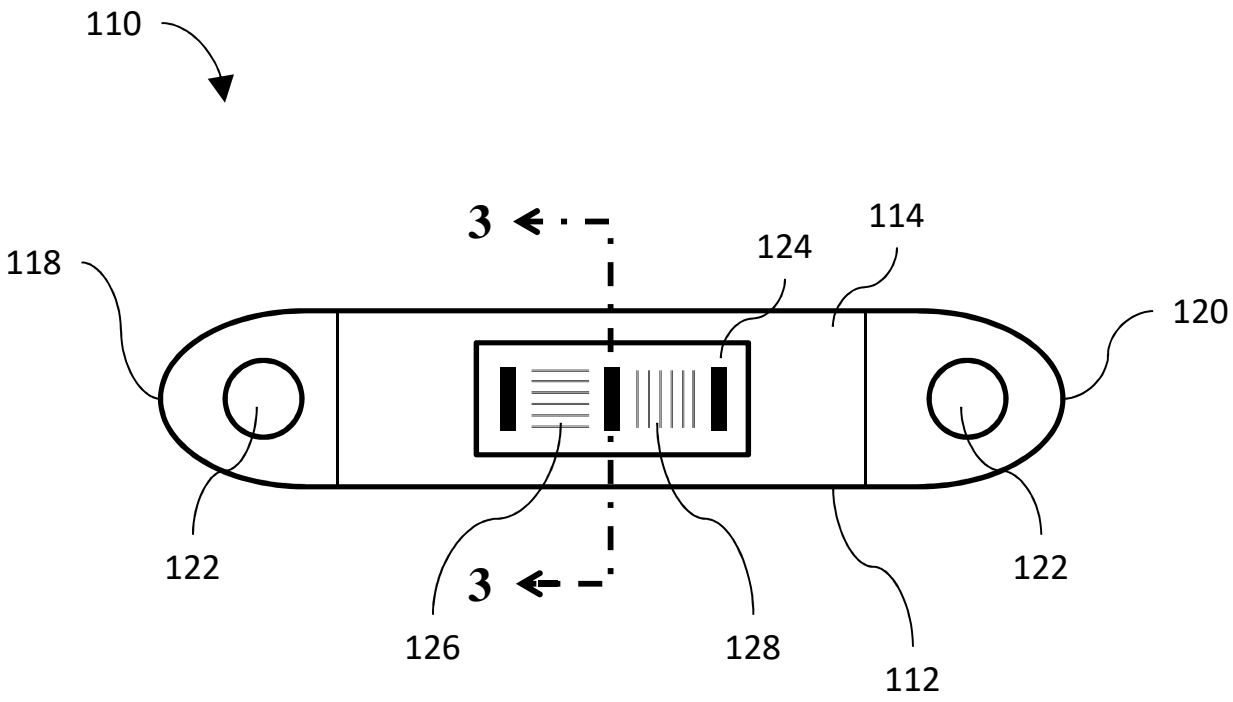

FIG. 2

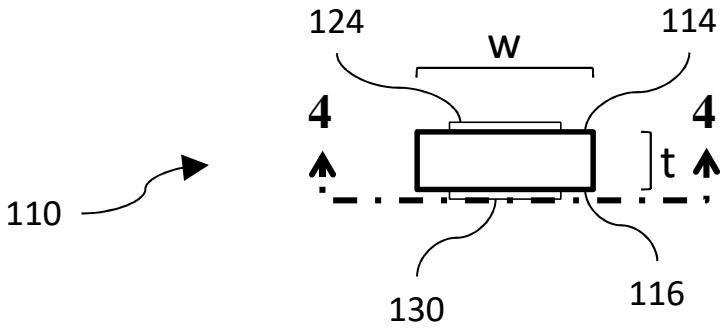

FIG. 3

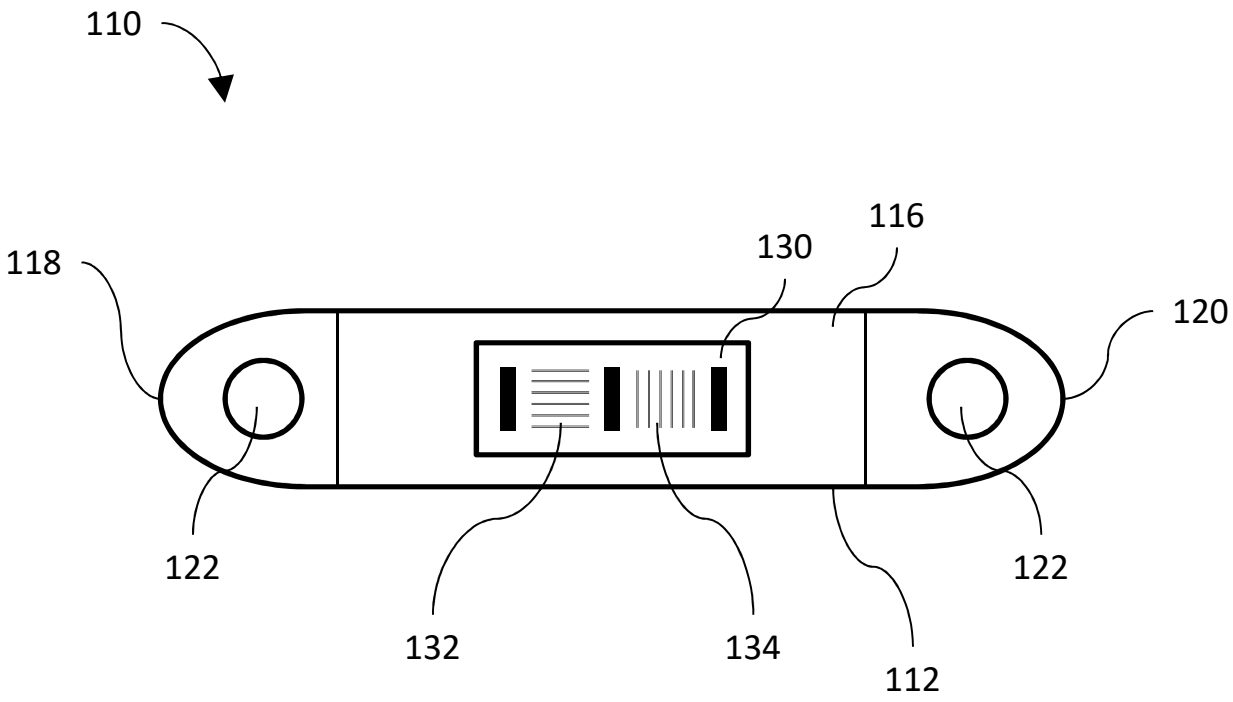

FIG. 4

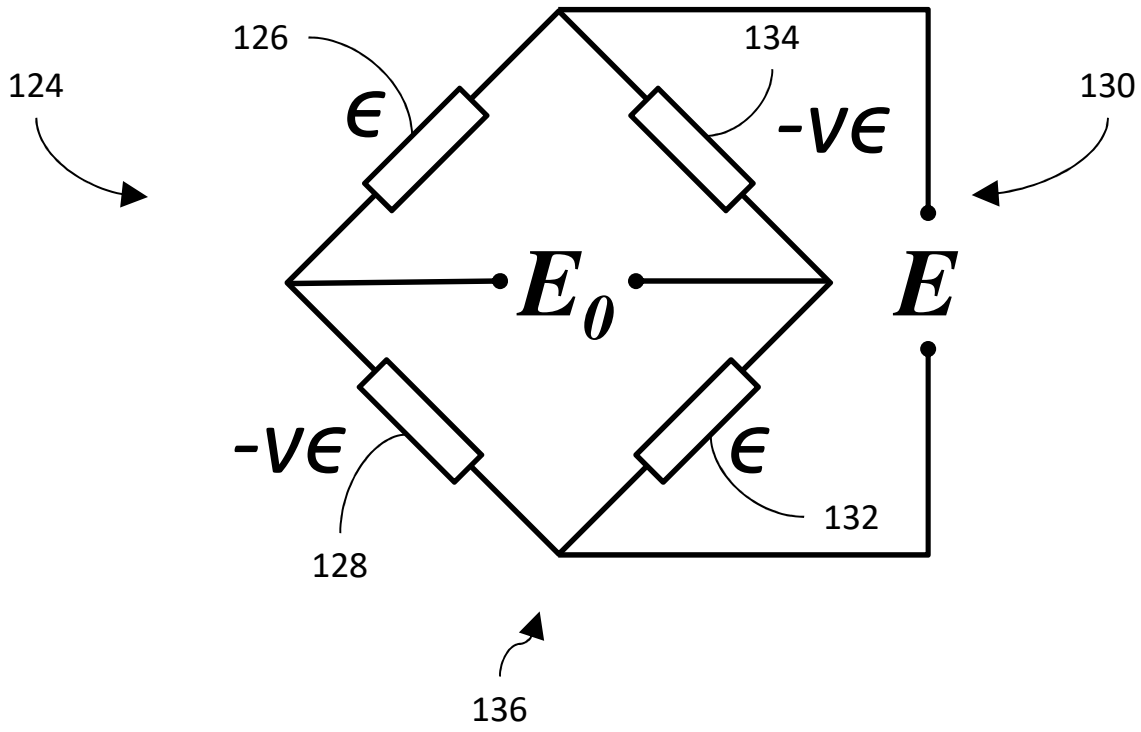
126
134
124
130
ϵ
$-V\epsilon$
E_0
E
$-V\epsilon$
ϵ
132
128
136

FIG. 5

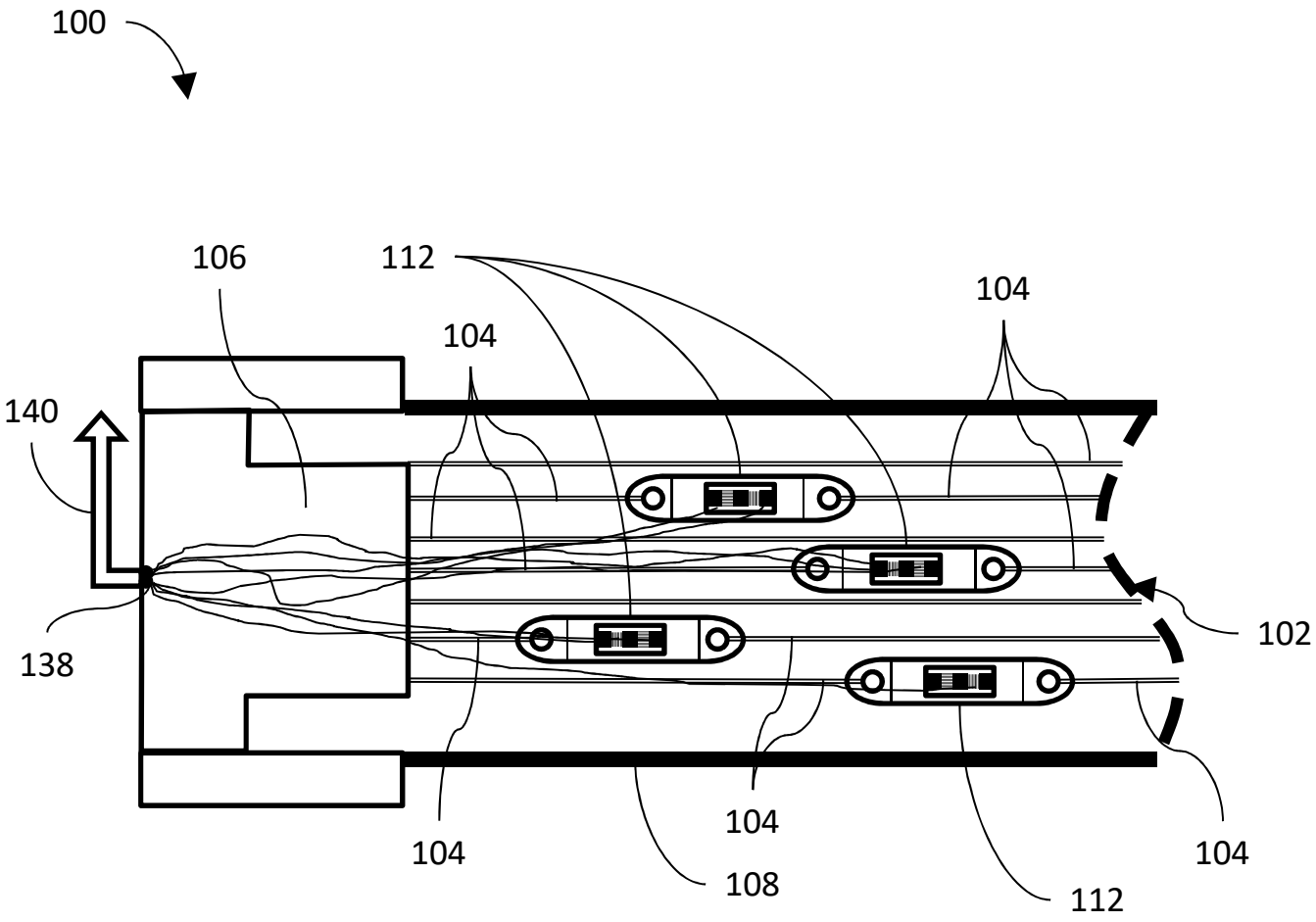

FIG. 6

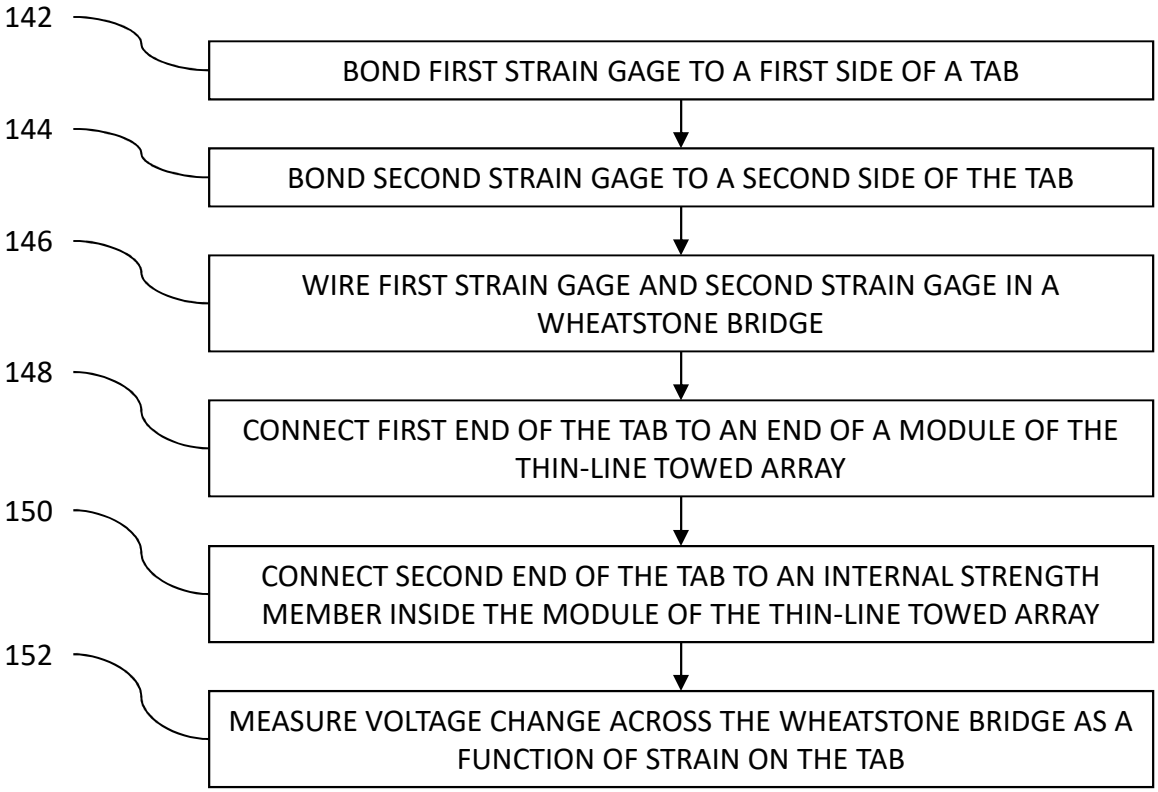
142
BOND FIRST STRAIN GAGE TO A FIRST SIDE OF A TAB
144
BOND SECOND STRAIN GAGE TO A SECOND SIDE OF THE TAB
146
WIRE FIRST STRAIN GAGE AND SECOND STRAIN GAGE IN A WHEATSTONE BRIDGE
148
CONNECT FIRST END OF THE TAB TO AN END OF A MODULE OF THE THIN-LINE TOWED ARRAY
150
CONNECT SECOND END OF THE TAB TO AN INTERNAL STRENGTH MEMBER INSIDE THE MODULE OF THE THIN-LINE TOWED ARRAY
152
MEASURE VOLTAGE CHANGE ACROSS THE WHEATSTONE BRIDGE AS A FUNCTION OF STRAIN ON THE TAB

FIG. 7