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(54) **PHALANGE TACTILE LOAD CELL**

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G01D 7/00 (2006.01)

(52) **U.S. Cl.** **73/862.041**

(58) **Field of Classification Search** 73/862.041–862.045
See application file for complete search history.

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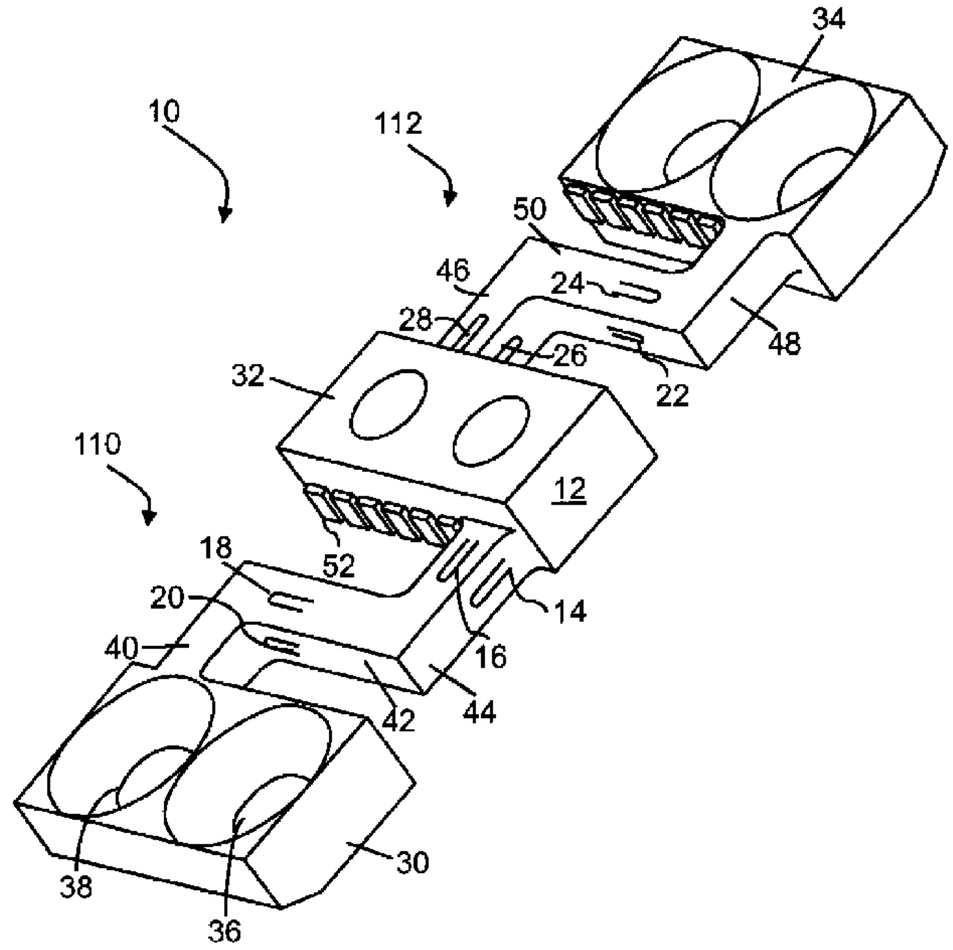
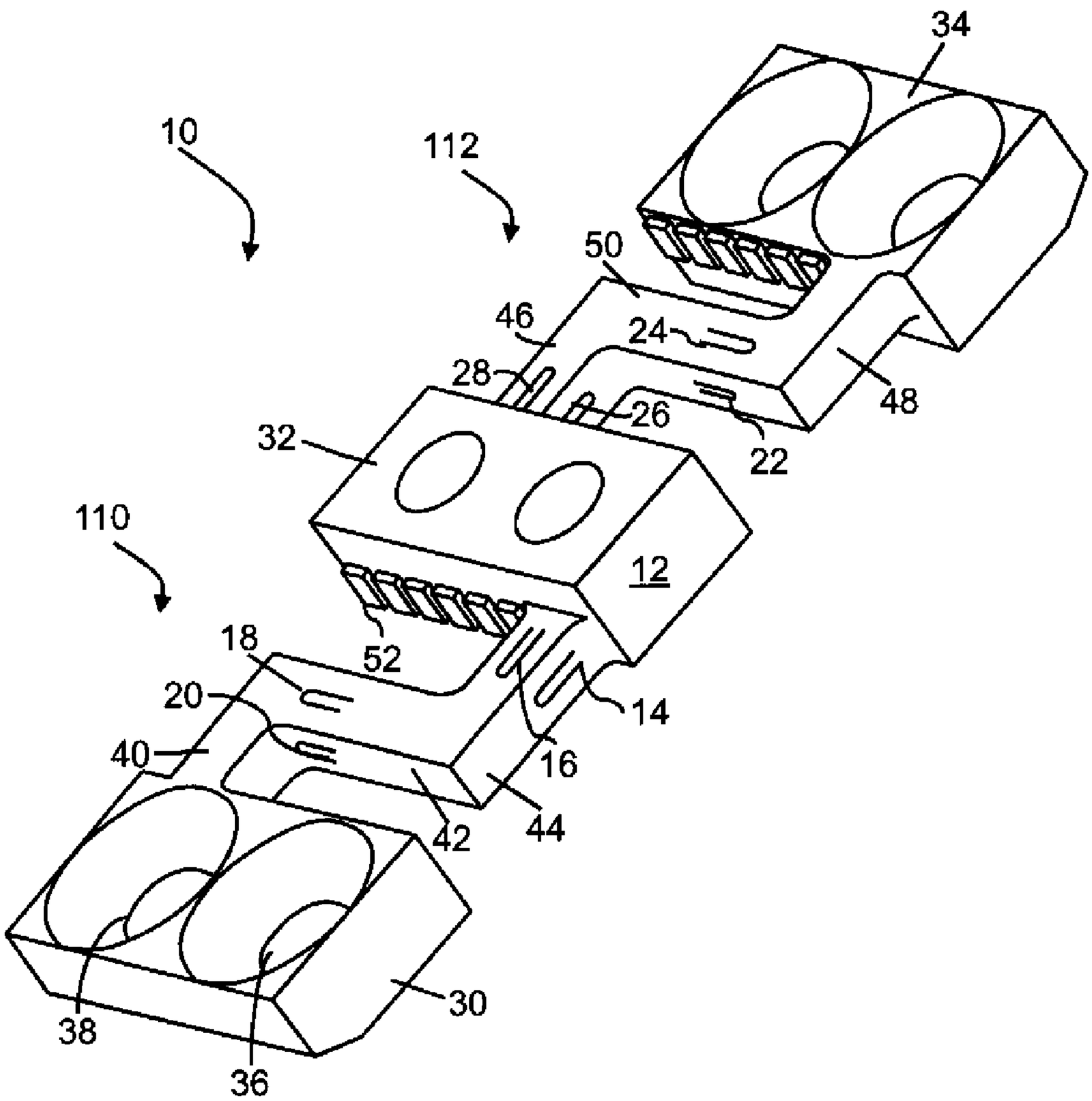
(57) **ABSTRACT**

A tactile load cell that has particular application for measuring the load on a phalange in a dexterous robot system. The load cell includes a flexible strain element having first and second end portions that can be used to mount the load cell to the phalange and a center portion that can be used to mount a suitable contact surface to the load cell. The strain element also includes a first S-shaped member including at least three sections connected to the first end portion and the center portion and a second S-shaped member including at least three sections coupled to the second end portion and the center portion. The load cell also includes eight strain gauge pairs where each strain gauge pair is mounted to opposing surfaces of one of the sections of the S-shaped members where the strain gauge pairs provide strain measurements in six-degrees of freedom.

20 Claims, 3 Drawing Sheets

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112
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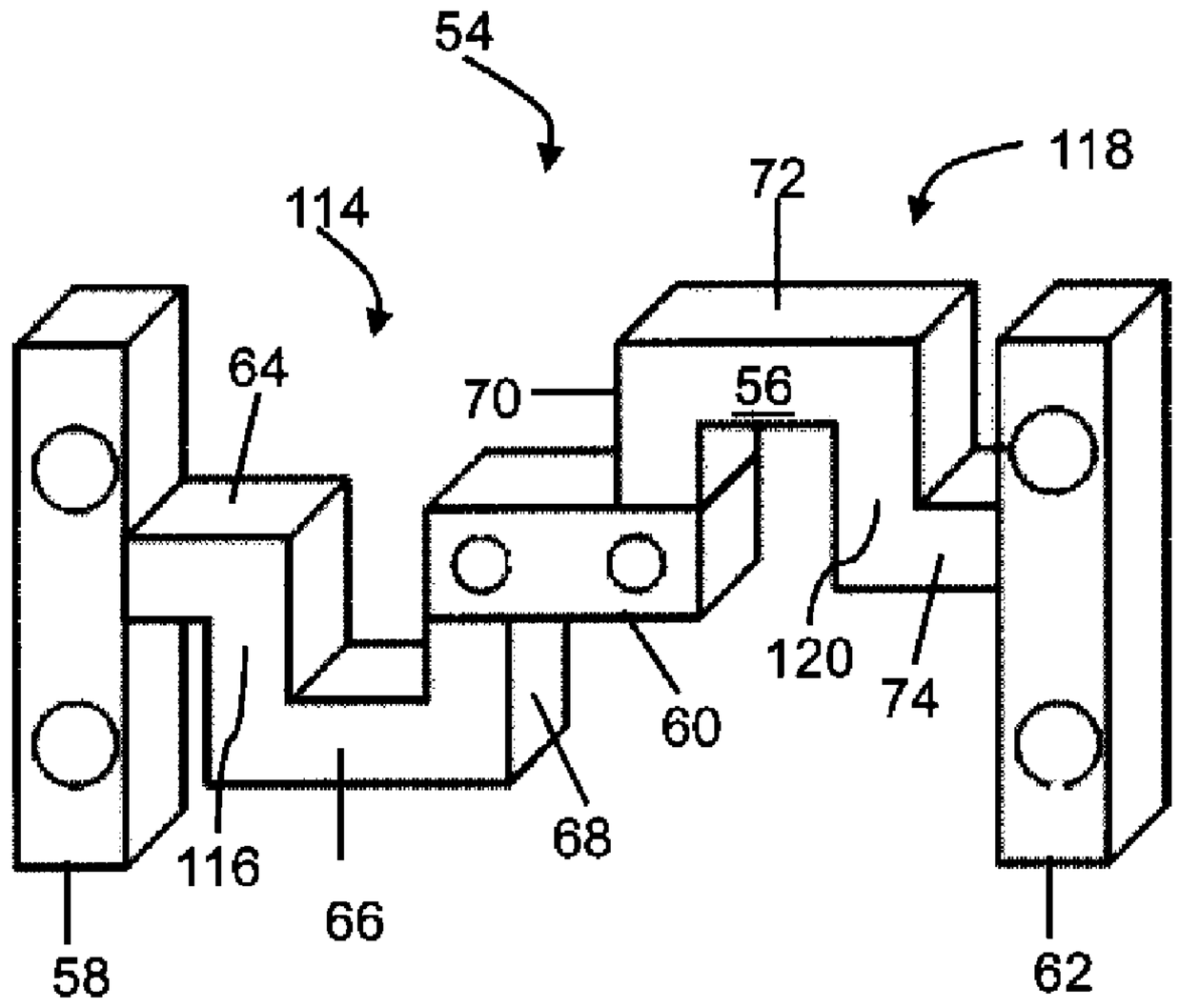
FIG. 1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114
72
118
64
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116
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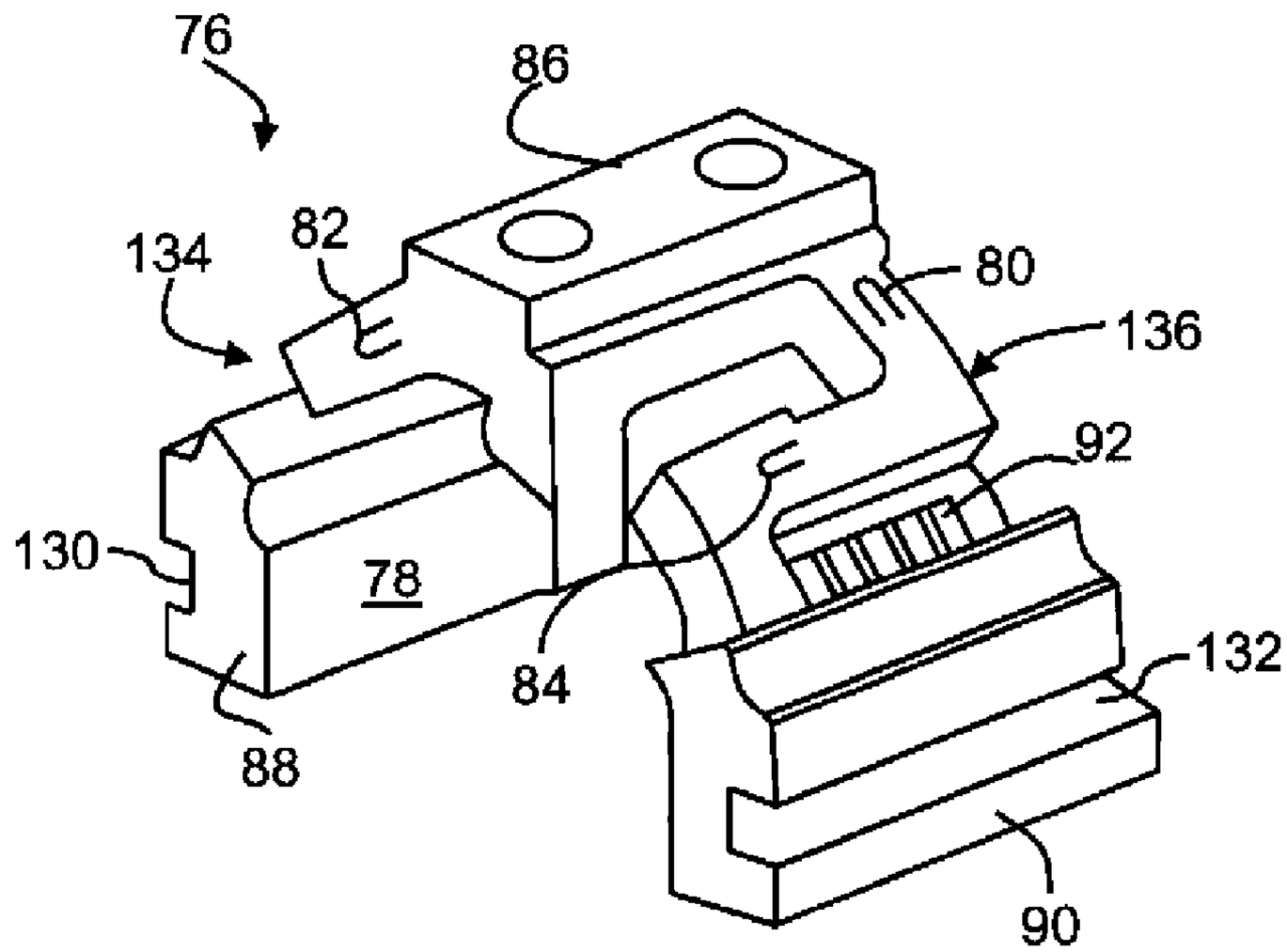
FIG. 2


76
86
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134
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136
92
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132
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90

FIG. 3

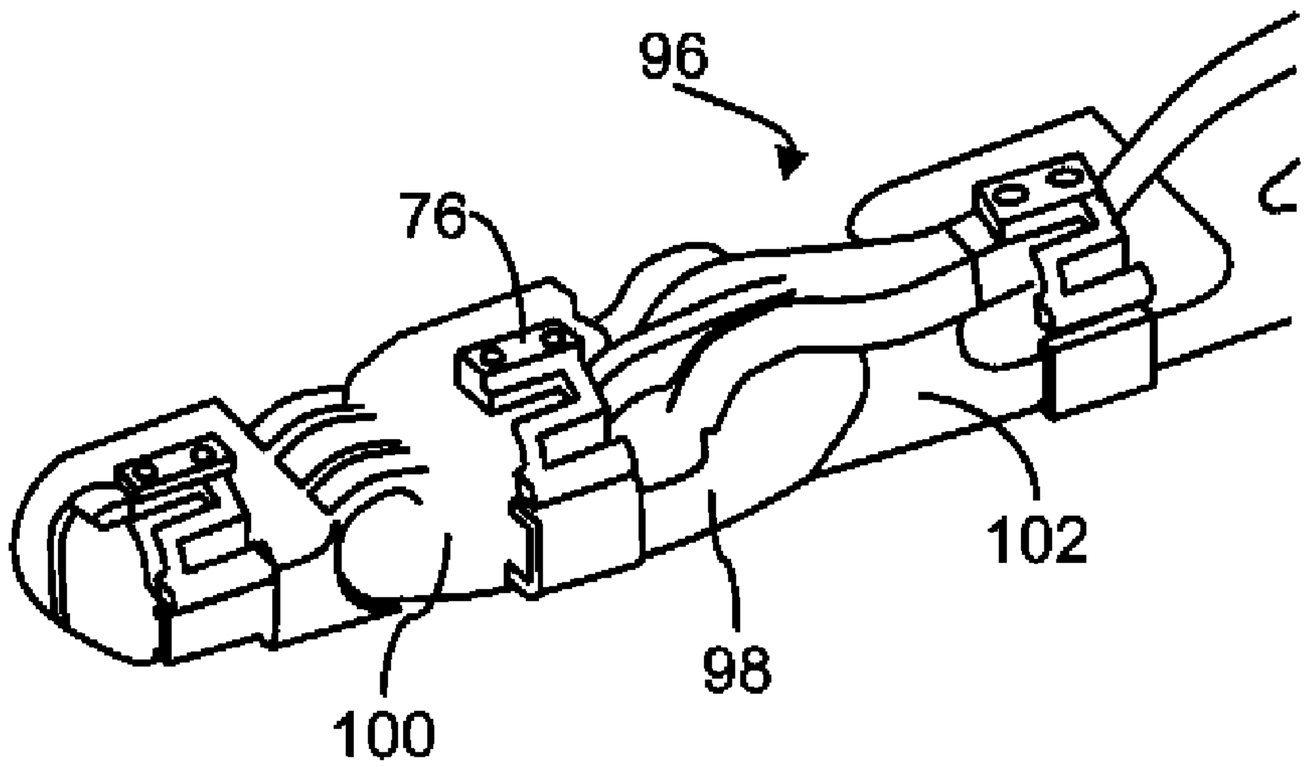

FIG. 4

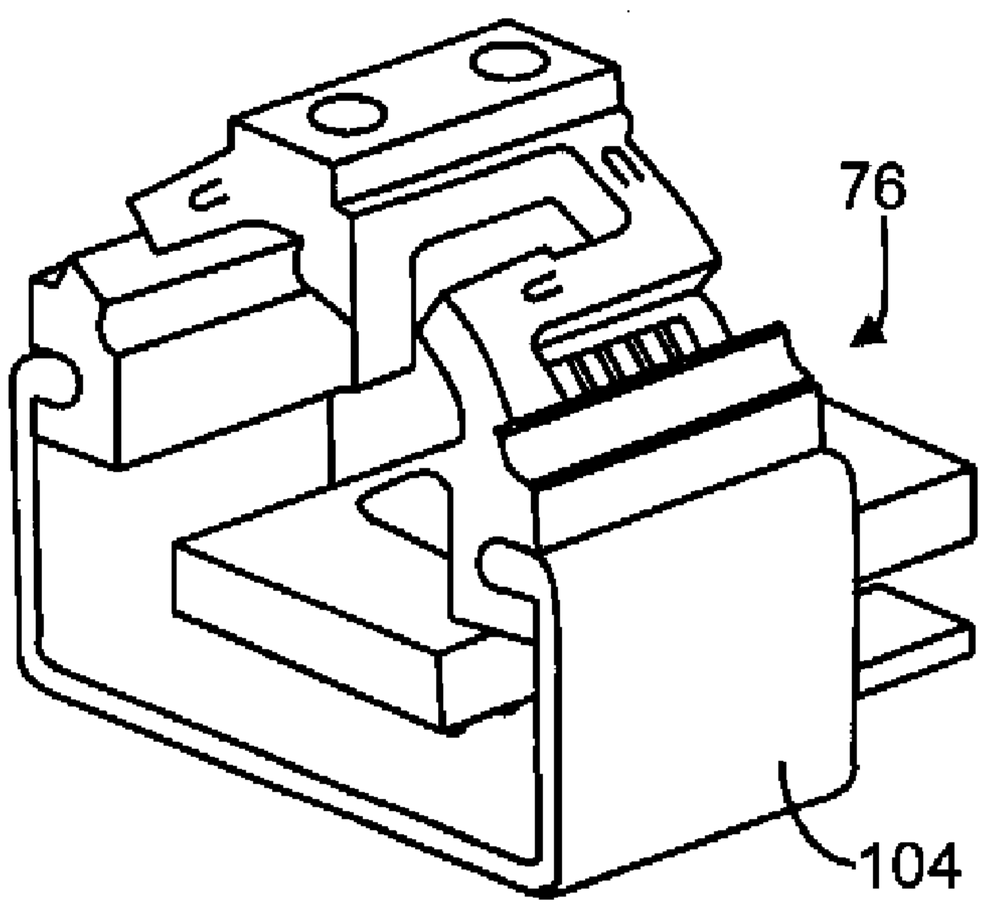

FIG. 5

PHALANGE TACTILE LOAD CELL

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The invention described herein may be manufactured and used by or for the U.S. Government for U.S. Government (i.e., non-commercial) purposes without the payment of royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to a load cell and, more particularly, to a tactile load cell for measuring the load on a phalange of a robotic finger or miniature manipulator where the load cell measures loads in six-degrees of freedom.

2. Description of the Related Art

Modern times have seen an increasing use of dexterous robot systems, especially in applications such as assembly lines and welding lines of manufacturing plants. This can be attributed to the high degree of precision and efficiency with which robots work. One latest development has been the introduction of autonomous robots, that is, robots which can perform desired tasks in unstructured environments without continuous human guidance. In applications where robotic arms are used, autonomous task control of the robotic system can be improved by obtaining detailed information about the load experienced at each contact point of the fingers attached to the arms. Monitoring the load acting on each section of a finger helps to ensure that the proper force is being exerted to accomplish a particular task. Further, unexpectedly high or low load observations can be used to identify malfunctions or undesirable conditions, such as slippage.

One existing technique used to measure the load experienced on the fingers of a robotic hand includes single axis contact sensors. However, the inability of such sensors to measure forces acting along more than one axis compromises the load resolution provided by the sensors.

Another known system uses commercial load cells to measure the load value. However, the load cells used in such systems typically have unacceptable sizes and cannot be housed inside every section of a finger of the robotic hand.

SUMMARY OF THE INVENTION

In accordance with the teachings of the present invention, a tactile load cell is disclosed that has particular application for measuring the load on a phalange in a dexterous robot system. The load cell includes a flexible strain element having first and second end portions that can be used to mount the load cell to the phalange and a center portion that can be used to mount a suitable contact surface to the load cell. The strain element also includes a first S-shaped member including at least three sections connected to the first end portion and the center portion and a second S-shaped member including at least three sections coupled to the second end portion and the center portion. The load cell also includes eight strain gauge pairs where each strain gauge pair is mounted to opposing surfaces of one of the sections of the S-shaped members where the strain gauge pairs provide strain measurements in six-degrees of freedom.

Additional features of the present invention will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a tactile load cell for a robotic hand, according to one embodiment;

FIG. **2** illustrates a tactile load cell for a robotic hand, according to another embodiment;

FIG. **3** illustrates a tactile load cell for a robotic hand, according to another embodiment;

FIG. **4** is a perspective view of a finger for a dexterous robot system that employs the tactile load cell shown in FIG. **3**; and

FIG. **5** is a perspective view of the load cell shown in FIG. **4** separated from the phalange and mounted to a mounting element in the phalange.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The following discussion of the embodiments of the invention directed to a tactile load cell is merely exemplary in nature, and is in no way intended to limit the invention or its applications or uses. For example, the tactile load cell of the invention has specific application for measuring the load on a phalange of a robotic finger. However, as will be appreciated by those skilled in the art, the tactile load cell of the invention may have other applications.

FIG. **1** is a perspective view of a tactile load cell **10** that has particular application to measure the load on a phalange of a dexterous robot system. As will be discussed below, the load cell **10** is able to simultaneously measure force in six directions, namely, three linear directions and three rotational directions. The load cell **10** includes a single body strain element **12** made of a suitable flexible material, such as aluminum. As will be discussed below, the strain element **12** is designed to maximize the measureable bending strain within the range of design loads, and within the limited space available on the phalanges of the dexterous robot system. The strain element **12** can be a single piece member manufactured or molded from the flexible material, or can be an assembly of the various elements discussed below coupled together by a suitable technique. The strain element **12** includes a first end mounting portion **30** and a second end mounting portion **34** having holes **36** and **38** that allow the load cell **10** to be mounted at a desired location. The strain element **12** also includes a central mounting portion **32** provided to mount a suitable contact surface to the load cell **10**.

The strain element **12** also includes a first S-shaped member **110** coupled to the first end mounting portion **30** and the central mounting portion **32** and a second S-shaped member **112** coupled to the second end mounting portion **34** and the central mounting portion **32**, as shown. The S-shaped member **110** includes sections **40**, **42** and **44** and the S-shaped member **112** includes sections **46**, **48** and **50**. In this non-limiting embodiment, the sections **40-50** are square or rectangular in cross-section, however, other shapes may be equally applicable.

In order to measure the strain on the S-shaped members **110** and **112**, strain gauge pairs are provided on certain ones of the sections **40-50**. Particularly, strain gauge pair **14** is provided on opposing sides of the section **44**, strain gauge pair **16** is provided on the other opposing sides of the section **44**, strain gauge pair **18** is provided on opposing sides of the section **42**, strain gauge pair **20** is provided on the other opposing sides of the section **42**, strain gauge pair **22** is provided on opposing sides of the section **50**, strain gauge pair **24** is provided on the other opposing sides of the section **50**, strain gauge pair **26** is provided on opposing sides of the section **46** and strain gauge pair **28** is provided on the other

opposing sides of the section **46**. Thus, any flexing or bending of the S-shape members **110** and **112** in six-degrees of freedom will be measured by the appropriate strain gauge pairs. In one non-limiting embodiment, the strain gauge pairs **14-28** are semiconductor strain gauges, although other types of strain gauges may be applicable.

A plurality of electrical contactors **52** are provided on the mounting portions **30**, **32** and **34** that provide an electrical connection to the strain gauge pairs **14-28**, and allow connections from the load cell **10** to control circuitry (not shown).

FIG. **2** is a perspective view of a tactile load cell **54** similar to the load cell **10** and based on the same principals for providing measurement of strain in six-degrees of freedom. In this embodiment, the load cell **54** includes a strain element **56** having end mounting portions **58** and **62** and center mounting portion **60**. Further, the strain element **56** includes a first curved member **114** having four rectangular shaped sections **64**, **66**, **68** and **116** and a second curved member **118** having four rectangular shaped sections **70**, **72**, **74** and **120**. The first curved member **114** is coupled to the end portion **58** and the center portion **60** and the second curved member **118** is coupled to the end portion **62** and the center portion **60**. The strain element **56** can be a single piece member molded or manufactured of a single piece of flexible material, such as aluminum, or can be an assembly of parts, where each of the first end portion **58**, the second end portion **62**, the center portion **60**, the first curved portion **114**, and the second curved member **118** are all separate members assembled together in a suitable manner. As with the load cell **10**, strain gauge pairs are provided at the appropriate location of the sections **64-74**, **116** and **120** to measure the strain in the six-degrees of freedom.

FIG. **3** is a perspective view of a tactile load cell **76** having a strain element **78** shaped as an arch. The load cell **76** has the same elements as the load cell **10**, but is formed in the arched configuration to better mount to a particular phalange of a dexterous robot system. Particularly, the load cell **76** includes end portions **88** and **90** including slots **130** and **132**, respectively, for mounting the load cell **76** to the phalange. Further, the strain element **78** includes a center portion **86** including holes for securing a suitable contact surface to the load cell **76**. The load cell **76** also includes a first S-shaped member **134** mounted to the end portion **88** and the center portion **86**, and having three sections forming a curved S-shape, and a second S-shaped member **136** mounted to the end portion **90** and the center portion **86**, and having three sections forming a curved S-shape. Further, eight strain gauge pairs, for example, strain gauge pairs **80**, **82** and **84**, are coupled to the S-shaped members **134** and **136** to measure the strain in six-degrees of freedom.

The load cell **76** also includes a flex circuit **92** in place of conventional wires to provide the electrical connection between the strain gauges and other electronic circuitry. The flex circuit **92** forms part of the arch shape of the strain element **56**.

FIG. **4** is a perspective view of a finger **96** that is part of a robotic hand in a dexterous robot system. The finger **96** includes various phalanges **98** connected by rotating joints **100** and **102**. The finger **96** includes three of the load cells **76** mounted to each phalange **98**. FIG. **5** is a perspective view of one of the load cells **76** mounted to a mounting element **104** where the element **104** is shaped to be positioned within the slots **130** and **132**. The arched configuration of the load cell **76** is specifically for the shape of the phalange **98** for this particular application.

The load cells are used to measure the load experienced by each finger as the robotic hand tries to perform as task. As the fingers experience a load, the strain element gets distorted. The distortion of the strain element is captured by the strain gauges mounted on the strain element and is converted into an electric signal. The signal is amplified using a half bridge circuit. However, it will be readily apparent to any person with ordinary skill in the art that the signal of the strain gauges can be amplified by means other than the one discussed in the embodiment given above. The signals from the load cell can be used to interpret a variety of information such as the nature and direction of the force acting on the finger, whether there is slippage or not, or whether the finger is pointing or grasping. The strain gauges are used in pairs which enables them to capture bending moments. The load cell is calibrated before being mounted in the robotic hand. During calibration, a known force is applied on the load cell. The signal of each strain gauge is noted and the combined signal is compared with the known force value. A multiplying factor, that is, the value by which the load cell signal is to be multiplied to get the actual force, is calculated based on this comparison. This multiplying factor is retained for use load cell is used in the robotic hand.

Various embodiments of the present invention offer one or more advantages. The present invention provides a robotic hand and a load cell used in it. The load cell of the present invention is of reduced size and is compact enough to fit inside a finger of the robotic hand. Further, the load cell configured to have six-degrees of freedom, and thus provides both direction and orientation information for applied loads.

The foregoing discussion discloses and describes merely exemplary embodiments of the present invention. One skilled in the art will readily recognize from such discussion and from the accompanying drawings and claims that various changes, modifications and variations can be made therein without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A tactile load cell comprising:

a flexible strain element including a first end portion, a second end portion and a center portion, said strain element further including a first S-shaped member having at least three sections and being coupled to the first end portion and the center portion and a second S-shaped member having at least three sections and being coupled to the second end portion and the center portion; and

a plurality of strain gauge pairs mounted to the first and second S-shaped members where each strain gauge pair is mounted to opposing sides of one of the sections of the S-shaped members, wherein at least one of the strain gauge pairs is mounted to opposing sides of one of the three sections of the first or second S-shaped member and another of the strain gauge pairs is mounted to two other opposing sides of the same section that the at least one strain gauge pair is mounted to.

2. The load cell according to claim **1** wherein the plurality of strain gauge pairs is eight strain gauge pairs providing strain measurements in six-degrees of freedom.

3. The load cell according to claim **2** wherein a first strain gauge pair is mounted to opposing surfaces of a first section of the first S-shaped member, a second strain gauge pair is mounted to two other opposing surfaces of the first section of the first S-shaped member, a third strain gauge pair is mounted to opposing surfaces of a second section of the first S-shaped member, a fourth strain gauge pair is mounted to two other opposing surfaces of the second section of the first S-shaped member, a fifth strain gauge pair is mounted to opposing surfaces of a first section of the second S-shaped

member, a sixth strain gauge pair is mounted to two other opposing surfaces of the first section of the second S-shaped member, a seventh strain gauge pair is mounted to opposing surfaces of the second section of the second S-shaped member and an eighth strain gauge pair is mounted to two other opposing surfaces of the second section of the second S-shaped member.

4. The load cell according to claim **1** wherein the sections of the first and second S-shaped members are rectangular in cross-section.

5. The load cell according to claim **1** wherein the strain element is made of aluminum.

6. The load cell according to claim **1** wherein the first and second end portions and the middle portion include mounting holes for mounting the load cell to a robotic finger.

7. The load cell according to claim **1** wherein the first and second end portions include coupling slots.

8. The load cell according to claim **1** wherein the strain element has a general U-shape.

9. The load cell according to claim **1** wherein the first and second S-shaped members each include four separate sections.

10. The load cell according to claim **1** wherein the load cell is part of a phalange in a dexterous robotic system that measures load on the phalange.

11. A tactile load cell comprising:

a flexible strain element including a first end portion, a second end portion and a center portion, said strain element further including a first S-shaped member including three sections and being coupled to the first end portion and the center portion and a second S-shaped member including three sections and being coupled to the second end portion and the center portion, said first and second S-shaped members having a curved configuration so that the strain element has a general U-shape; and

eight strain gauge pairs mounted to the first and second S-shaped members where each strain gauge pair is mounted to opposing sides of one of the sections of the S-shaped members and where the first S-shaped member includes four of the strain gauge pairs and the second S-shaped member includes the other four of the strain gauge pairs, said eight strain gauge pairs providing strain measurements in six-degrees of freedom, wherein at least one of the strain gauge pairs is mounted to opposing sides of one of the three sections of the first or second S-shaped member and another of the strain gauge pairs is mounted to two other opposing sides of the same section that the at least one strain gauge pair is mounted to.

12. The load cell according to claim **11** a first strain gauge pair is mounted to opposing surfaces of a first section of the first S-shaped member, a second strain gauge pair is mounted to two other opposing surfaces of the first section of the first S-shaped member, a third strain gauge pair is mounted to opposing surfaces of a second section of the first S-shaped member, a fourth strain gauge pair is mounted to two other opposing surfaces of the second section of the first S-shaped member, a fifth strain gauge pair is mounted to opposing surfaces of a first section of the second S-shaped member, a sixth strain gauge pair is mounted to two other opposing surfaces of the first section of the second S-shaped member, a seventh strain gauge pair is mounted to opposing surfaces of the second section of the second S-shaped member and an eighth strain gauge pair is mounted to two other opposing surfaces of the second section of the second S-shaped member.

13. The load cell according to claim **11** wherein the sections of the first and second S-shaped members are rectangular in cross-section.

14. The load cell according to claim **11** wherein the strain element is made of aluminum.

15. The load cell according to claim **11** wherein the load cell is part of a phalange in a dexterous robotic system that measures load on the phalange.

16. A tactile load cell for measuring strain in a phalange of a dexterous robot system, said load cell comprising:

a flexible strain element including a first end portion, a second end portion and a center portion, said strain element further including a first S-shaped member having at least three sections and being coupled to the first end portion and the center portion and a second S-shaped member having at least three sections and being coupled to the second end portion and the center portion; and

eight strain gauge pairs mounted to the first and second S-shaped members such that each strain gauge pair is mounted to opposing sides of one of the sections of the S-shaped member, wherein the first S-shaped member includes four of the strain gauge pairs and the second of the S-shaped members includes the other four of the strain gauge pairs and wherein the strain gauge pairs provide strain measurements and six-degrees of freedom, wherein at least one of the strain gauge pairs is mounted to opposing sides of one of the three sections of the first or second S-shaped member and another of the strain gauge pairs is mounted to two other opposing sides of the same section that the at least one strain gauge pair is mounted to.

17. The load cell according to claim **16** a first strain gauge pair is mounted to opposing surfaces of a first section of the first S-shaped member, a second strain gauge pair is mounted to two other opposing surfaces of the first section of the first S-shaped member, a third strain gauge pair is mounted to opposing surfaces of a second section of the first S-shaped member, a fourth strain gauge pair is mounted to two other opposing surfaces of the second section of the first S-shaped member, a fifth strain gauge pair is mounted to opposing surfaces of a first section of the second S-shaped member, a sixth strain gauge pair is mounted to two other opposing surfaces of the first section of the second S-shaped member, a seventh strain gauge pair is mounted to opposing surfaces of the second section of the second S-shaped member and an eighth strain gauge pair is mounted to two other opposing surfaces of the second section of the second S-shaped member.

18. The load cell according to claim **16** wherein the strain element has a general U-shape.

19. The load cell according to claim **16** wherein the first and second end portions include coupling slots.

20. The load cell according to claim **16** wherein the strain element is made of aluminum.

* * * * *