

PIEZO-RESISTIVE FORCE SENSOR WITH BUMPS ON MEMBRANE STRUCTURE

Field of the Invention

[0001] The present invention generally relates to devices for sensing a force, and more particularly to a piezo-resistive force sensor for vehicle brake applications.

Background of the Invention

[0002] Force sensing devices such as piezo-resistive force sensor have become more popular in electro-mechanical systems because they provide precise and reliable force sensing performance in a compact package. Furthermore, the compact package of the piezo-resistive force sensor facilitates easy integration into the electro-mechanical systems. The piezo-resistive force sensor operates on the principle that the silicon implanted piezo-resistors vary their resistance when deformed by a force. Typically, these piezo-resistors are fabricated in a silicon die/chip, where the silicon die/chip is configured to be flexed or compressed by the force.

[0003] Vehicles, as transport means, have become an important part of society. Typically, driving a vehicle requires the constant use of brakes to slow down or stop the vehicle. The inefficiency of a braking system can result in traffic accidents and other undesirable consequences. Therefore, knowledge and control of the braking force is important to improve the efficiency of the braking system. The piezo-resistive force sensors are integrated in vehicle braking systems to measure and facilitate control of the braking force, thus improving the overall braking performance.

[0004] Figure 1 illustrates a known piezo-resistive force sensor 1 for brake application. The force sensor 1 comprises a plunger 2, a flexible membrane 4, a silicon die 10, and a support plate 7. The plunger 2 is configured to receive a force from a load, wherein the plunger 2 transmits the force to the membrane 4. In particular, the lower surface of the plunger 2 has a ring-shaped bump 3 that complementarily fits into a ring-shaped groove 5 at the upper surface of the membrane 4. The membrane 4 is supported by the fixed support plate 7, wherein the lower surface of the membrane 4 has another ring-shaped groove 6 configured to allow a ring-shaped bump 8 on the support plate 7 to fit

into. Furthermore, the lower surface of the membrane 4 has a centrally disposed convex step 9 that secures the silicon die 10 between the membrane 4 and the support plate 7.

[0005] The configuration of the force sensor 1 works under the principles of a lever mechanism, wherein the bump 8 on the support plate 7 acts as a fulcrum element for the membrane 4, and wherein the membrane 4 acts as a lever element. When the plunger 2 receives a force from the load, the force is transmitted to the membrane 4, causing the membrane 4 to flex. The flexing of the membrane 4 bends and/or compresses the silicon die 10, thus resulting in the silicon die 10 making a measurement of the force from the load. During this operation, a large proportion of the force applied on the membrane 4 is transmitted from the groove 5 to the groove 6. The force applied on both grooves (5, 6) of the membrane 4 creates a high level of stress on the membrane 4. Thus, the membrane 4 is easily subjected to fracture and other stress-induced deformation which reduce the durability and reliability of the structure. Furthermore, the accuracy of the force measurement also decreases.

[0006] Therefore, there is an imperative need to have a durable and reliable piezo-resistive force sensor to provide precise measurements of force. The purpose of this invention is to devise a sensor satisfying the above-mentioned requirement. Other advantages of this invention will be apparent with reference to the detailed description.

Summary of the Invention

[0007] The present invention provides a device for sensing a force, and more particularly to a piezo-resistive force sensor for use in a vehicle brake system to improve the overall braking performance.

[0008] Accordingly, in one aspect, the present invention provides a device for measuring the force from a load, the device comprising a plunger configured to receive the force from the load, wherein the lower surface of the plunger has a ring-shaped first groove; a disc-shaped membrane having an upper surface and lower surface, wherein the membrane is flexible according to the force received by the plunger, wherein the upper surface of the membrane has a ring-shaped first bump, the first bump configured to complementarily fit into the first groove on the lower surface of the plunger, and wherein the lower surface of the membrane has a ring-shaped second bump; a sensing means centrally disposed on the membrane, wherein the sensing means measures the force of the

load when being bent or compressed caused by the membrane; a support plate having a ring-shaped second groove that is configured so that the second bump on the lower surface of the membrane can complementarily fit into; and whereby the force received by the plunger from the load is transmitted to the membrane, causing the membrane to flex, which in turn causes the bending or compressing of the sensing means, resulting in the measurement of the force from the load.

[0009] In another aspect, the present invention provides braking system coupled to at least one wheel of a vehicle to control the braking force thereupon, the braking system comprising a pedal for inputting an initial braking pressure to the at least one wheel; a braking device coupled to the at least one wheel, wherein the braking device is configured to apply the initial braking pressure on the at least one wheel, and further wherein the braking device comprises a sensor to measure the braking pressure applied to the at least one wheel, the sensor comprising, a plunger configured to receive the applied braking force, wherein the lower surface of the plunger has a ring-shaped first groove; a disc-shaped membrane having an upper surface and lower surface, wherein the membrane is flexible according to the applied braking force received by the plunger, wherein the upper surface of the membrane has a ring-shaped first bump, the first bump configured to complementarily fit into the first groove on the lower surface of the plunger, and wherein the lower surface of the membrane has a ring-shaped second bump; a sensing means centrally disposed on the membrane, wherein the sensing means measures the applied braking force when being bent or compressed caused by the membrane; a support plate having a ring-shaped second groove that is configured so that the second bump on the lower surface of the membrane can complementarily fit into; and whereby the applied braking force received by the plunger is transmitted to the membrane, causing the membrane to flex, which in turn causes the bending or compressing of the sensing means, resulting in the measurement of the applied braking force; and a control unit electrically coupled to the braking device to control the braking pressure on the at least one wheel, wherein the control unit is configured to receive the measurement of the applied braking force from the braking device, and to process the measurement of the applied braking force to control the braking pressure on the at least one wheel.

Brief Description of the Drawings

[0010] Preferred embodiments according to the present invention will now be described with reference to the Figures, in which like reference numerals denote like elements.

[0011] FIG 1 is an illustrative diagram showing the cross-sectional view of the piezo-resistive force sensor in accordance with one prior art embodiment.

[0012] FIG 2 is an illustrative diagram showing a perspective view of the unassembled force sensor in accordance with one embodiment of the present invention.

[0013] FIG 3 is an illustrative diagram showing a cross-sectional view of the unassembled force sensor in accordance with one embodiment of the present invention.

[0014] FIG 4 is an illustrative diagram showing the bottom perspective view of the membrane in FIG 2.

[0015] FIG 5 is an illustrative diagram showing the bottom plan view of the membrane in FIG 2.

[0016] FIG 6 is an illustrative diagram showing an enlarged cross-sectional view of the depression in the support plate in accordance with one embodiment of the present invention.

[0017] FIG 7 is an illustrative diagram showing a cross-sectional view of the assembled force sensor in accordance with one embodiment of the present invention.

[0018] FIG 8 is an illustrative diagram showing a cross-sectional view of the assembled force sensor in accordance with one alternative embodiment of the present invention.

[0019] FIG 9 is an illustrative diagram showing a cross-sectional view of the assembled force sensor in accordance with another alternative embodiment of the present invention.

[0020] FIG 10 is a block diagram illustrating a vehicle braking system in accordance with one embodiment of the present invention.

[0021] FIG 11 is a simplified diagram illustrating a vehicle braking device in accordance with one embodiment of the present invention.

[0022] FIG 12 is a graphic simulation of the stress level on the membrane of the force sensor in accordance with one embodiment of the prior art.

[0023] FIG 13 is a graphic simulation of the reduced stress level on the membrane of the force sensor in accordance with one embodiment of the present invention.

Detailed Description of the Invention

[0024] The present invention may be understood more readily by reference to the following detailed description of certain embodiments of the invention.

[0025] Throughout this application, where publications are referenced, the disclosures of these publications are hereby incorporated by reference, in their entireties, into this application in order to more fully describe the state of art to which this invention pertains.

[0026] The present invention provides a force sensor **11** for measuring a force applied thereon. Referring to Figures 2 and 3, the force sensor **11** comprises a plunger **20**, a membrane **40**, a support plate **60**, and a silicon die **10**, wherein the force sensor **11** has a central axis A-A. The plunger **20**, the membrane **40**, and the support plate **60** is preferably made of steel or other types of metal, or metal alloys. The silicon die **10** is a sensor chip comprising piezo-resistors, wherein the resistance of the piezo-resistors varies according to the deformation of the silicon die **10**. It is contemplated that other types of sensors that deform to provide a force measurement could be used. For example a fiber Bragg grating (FBG) optical fiber sensor or a strain gauge.

[0027] Referring to Figures 2 and 3, the plunger **20** is a cup-shaped body having a center aligned to the central axis A-A. The bottom surface of the plunger **20** has a ring-shaped groove **22**, wherein the ring-shaped groove **22** has a center aligned to the central axis A-A. The membrane **40** is a disc-shaped body with a center aligned to the central axis A-A, wherein the membrane **40** has a ring-shape upper bump **42** at the upper surface and a ring-shape lower bump **44** at the lower surface. The upper bump **42** is an integral part of the membrane **40**, wherein the upper bump **42** has a center aligned to the central axis A-A. Similarly, the lower bump **44** is an integral part of the membrane **40**, wherein the lower bump **44** has a center aligned to the central axis A-A. In the present embodiment, the diameter of the ring-shaped upper bump **42** is less than the diameter of the ring-shaped lower bump **44**. Furthermore, the bottom surface of the membrane **40** has a convex step **46**, wherein the step **46** is centrally disposed on the bottom surface of the membrane **40**. The step **46** supports the silicon die **10** between the membrane **40** and the support plate **60**,

wherein the step 46, in use, facilitates the transmission of force to the silicon die 10. Referring to Figures 4 and 5, the lower bump 44 may comprise a plurality of gaps 48 that provide passages for electrical connectors to couple the silicon die 10 to other electronic components. Other methods of connecting the silicon die 10 to electronic components are possible, but will not be discussed in detail herein.

[0028] Referring back to Figures 2 and 3, the fixed support plate 60 is a disc-shaped body having a center aligned to the central axis A-A. A ring-shaped groove 62 is formed at the upper surface of the support plate 60, wherein the ring-shaped groove 62 has a center aligned to the central axis A-A. Referring to Figure 6, the support plate 60 may comprise a depression 64 for supporting the silicon die 10, wherein the silicon die 10 is secured between the depression 64 and the step 46 at the bottom of the membrane 40.

[0029] Figure 7 is a cross-sectional view of the configuration of the assembled force sensor 11. The upper surface of the plunger 20 is coupled to a load, wherein the plunger 20 receives a force from the load. The upper bump 42 of the membrane 40 is configured to complementarily fit into the groove 22 on the lower surface of the plunger 20. Furthermore, the lower bump 44 of the membrane 40 is configured to complementarily fit into the groove 62 at the upper surface of support plate 60. As discussed above, the silicon die 10 is disposed between the step 46 and the upper surface of the support plate 60.

[0030] The configuration of the assembled force sensor 11 operates under the principles of a lever mechanism, as discussed above. Without intention to be bound by any particular theory or principle, the membrane 40 performs both the lever and fulcrum functions. Specifically, the lower bump 44 of the membrane 40 acts as the fulcrum element that supports the membrane 40 on the support plate 60, and wherein the membrane 40 also acts as the lever element. When the plunger 20 receives a force from the load, the force is transmitted to the membrane 40, causing the membrane 40 to flex. The flexing of the membrane 40 bends and/or compresses the silicon die 10, resulting in the measurement of the force from the load by the silicon die 10. Typically, the force received by the plunger 20 is too large for the silicon die 10 to measure directly. Hence, the membrane 40 is configured to attenuate the actual amount of force from the plunger 20 for measurement by the silicon die 10. During flexing of the membrane 40, the upper bump 42 transmits a large proportion of the force to the lower bump 42, wherein a smaller proportion of the

force is transmitted to the silicon die 10. The thickness of the membrane 40 and the diameters of the ring-shaped bumps (42, 44) on the membrane 40 can be predetermined to ensure that the silicon die 10 measures the force from the load accurately and reliably. Furthermore, the step 46 may be provided to facilitate the compression on the silicon die 10. In the present configuration, the upper bump 42 and lower bump 44 are disposed on the membrane 40 to reduce the stress induced on the membrane 40 by the force transmitted from the plunger 20 and supporting plate 60. Hence, the reliability and durability of the force sensor 11 is significantly improved.

[0031] Mechanical simulations have been carried out to evaluate and compare the level of stress induced on the membrane. Figure 12 illustrates a partial view of the known force sensor 1, showing the simulation results of stress induced on the membrane 4. As described above, the membrane 4 has a groove 5 at the upper surface configured to complementarily receive a bump 3 on the plunger 2. Furthermore, the membrane 4 also has another groove 6 at the lower surface configured to complementarily receive a bump 8 on the support plate 7. When the plunger receives a force from the load, the portion 91 below the groove 5 is subjected to a high level of stress. Figure 13 is a partial view of the force sensor 11 of the present invention, showing the simulation results of stress induced on the membrane 40. In particular, Figure 13 shows that the stress level at the portion 92 below the upper bump 42 is significantly lower relative to Figure 12.

[0032] Figure 8 shows an alternative embodiment of the force sensor 11, wherein the silicon die 10 is directly mounted at the center of the lower surface of membrane 40'. When the plunger 20 receives a force and flexes the membrane 40', the flexing of the membrane 40' causes the silicon die 10 to bend accordingly. The bending of the silicon die 10 results in the measurement of the force from the load. Alternatively, the silicon die 10 could be mounted at the center of the upper surface membrane 40', wherein the flexing of the membrane 40' causes the silicon die 10 to bend.

[0033] Figure 9 shows another alternative embodiment of the force sensor 11, wherein the membrane 80 has an upper bump 82 at the upper surface and a lower bump 84 at the lower surface. In particular, the upper bump 82 is configured with a larger diameter relative to the lower bump 84. Furthermore, the upper bump 82 is configured to complementarily fit into the groove 72 at the lower surface of the plunger 70. The lower bump 84 is configured to complementarily fit into the groove 76 at the upper surface of the

support plate 78. The silicon die 10 is preferably centrally mounted on the upper surface of the membrane 80. When the plunger 70 receives a force and flexes the membrane 80, the flexed membrane 80 causes the silicon die 10 to bend accordingly. The bending of the silicon die 10 results in the measurement of the force from the load. Alternatively, the silicon die 10 could be centrally mounted on the lower surface of the membrane 80, wherein the flexing of the membrane 80 causes the silicon die 10 to bend.

[0034] In one embodiment, the force sensor 11 of the present invention can be used in a braking system 100 of a vehicle with brake by wire technology. Referring to Figure 10, the brake pedal 130 is electrically coupled to the plurality of braking devices 200 via a control unit 120. The control unit 120 receives the driver's input from the brake pedal 130 to control the operation of the plurality of braking devices 200. Furthermore, each braking device 200 comprises a force sensor 11 of the present invention, wherein the force sensor 11 measures the braking force of the wheel 110. Based on the driver's input and the vehicle's operation from the force sensors 11, the control unit 120 automatically adjusts the braking operation to maintain safety.

[0035] Figure 11 is a simplified diagram illustrating the components of a braking device 200. The braking device 200 comprises a disc 210 coupled to the wheel 110 of the vehicle, wherein the disc 210 rotates with the rotation of the wheel 110. Typically, the disc 210 is disposed between two pads 220, wherein the two pads 220 provide a clamping force on the disc 210 to apply a braking pressure on the wheel 110. A screw 230 is coupled to the pads 220, wherein the screw 230 can be driven to move the pads 220 relative to the disc 210. Furthermore, the screw 230 is coupled to the electric motors 240 via a reduction gear 250, wherein the reduction gear 250 is provided to transform the rotational motion of the electric motors 240 to the translation movement of the screw 230. The control unit 120 controls the electric motors 240 to generate or adjust the braking pressure on the wheel 110. In the present embodiment, the force sensor 11 is coupled to the reduction gear 250. In particular, the reduction gear 250 acts as a load on the plunger 20 of the force sensor 11, wherein the movement of the reduction gear 250 varies the load on the plunger 20 and changes the state of the silicon die 10. As a result, the silicon die 10 generates an electronic signal corresponding to the force applied from the reduction gear 250, wherein the electronic signal is transmitted to the control unit 120.

[0036] During a braking action, each of the wheels **110** may be subjected to different amounts of braking force, which may cause the vehicle to swerve or even overturn. The control unit **120** is provided to adjust the braking force on each wheel **110** based on the electronic signals received from each force sensor **11**. In particular, the control unit **120** receives and processes the electronic signals from the silicon die **10** of each force sensor **11**. Based on the electronic signals from the force sensor **11** and the input from the brake pedal **130**, the control unit **120** controls the electric motors **240** accordingly to apply the correct amount of braking pressure on each wheel **110**, thereby achieving a better braking performance for the vehicle. Although the foregoing description discloses a force sensor **11** for use in vehicle braking systems, it is apparent to one skill in the art that the force sensor **11** can be applied in any electro-mechanical system that measures and controls the application of force.

[0037] While the present invention has been described with reference to particular embodiments, it will be understood that the embodiments are illustrative and that the invention scope is not so limited. Alternative embodiments of the present invention will become apparent to those having ordinary skill in the art to which the present invention pertains. Such alternate embodiments are considered to be encompassed within the spirit and scope of the present invention. Accordingly, the scope of the present invention is described by the appended claims and is supported by the foregoing description.

CLAIMS

What is claimed is:

1. A device for measuring the force from a load, the device comprising:
 - a plunger configured to receive the force from the load, wherein the lower surface of the plunger has a ring-shaped first groove;
 - a disc-shaped membrane having an upper surface and lower surface, wherein the membrane is flexible according to the force received by the plunger,
 - wherein the upper surface of the membrane has a ring-shaped first bump, the first bump configured to complementarily fit into the first groove on the lower surface of the plunger, and
 - wherein the lower surface of the membrane has a ring-shaped second bump;
 - a sensing means centrally disposed on the membrane, wherein the sensing means measures the force of the load when being bent or compressed caused by the membrane;
 - a support plate having a ring-shaped second groove that is configured so that the second bump on the lower surface of the membrane can complementarily fit into; and
 - whereby the force received by the plunger from the load is transmitted to the membrane, causing the membrane to flex, which in turn causes the bending or compressing of the sensing means, resulting in the measurement of the force from the load.
2. The device according to claim 1 further comprising a convex step centrally disposed on the lower surface of the membrane, wherein the convex step secures the sensing means between the lower surface of the membrane and the support plate.
3. The device according to claim 2, wherein the support plate further comprises a depression configured for supporting the silicon die.

4. The device according to claim 2, wherein the ring-shaped second bump has at least one gap, wherein the at least one gap provides passage for an electrical connector to couple the silicon die to other electronic components.
5. The device according to claim 1, wherein the sensing means is centrally mounted on the upper surface of the membrane.
6. The device according to claim 1, wherein the sensing means is centrally mounted on the lower surface of the membrane.
7. The device according to claim 1, wherein the ring-shaped first bump has a smaller diameter than the ring-shaped second bump.
8. The device according to claim 1, wherein the ring-shaped first bump has a larger diameter than the ring-shaped second bump.
9. The device according to claim 1, wherein the sensing means is a silicon die with a plurality of integrated piezo-resistors, wherein the plurality of integrated piezo-resistors varies their resistance when bent or compressed.
10. A braking system coupled to at least one wheel of a vehicle to control the braking force thereupon, the braking system comprising:
 - a pedal for inputting an initial braking pressure to the at least one wheel;
 - a braking device coupled to the at least one wheel, wherein the braking device is configured to apply the initial braking pressure on the at least one wheel, and further wherein the braking device comprises a sensor to measure the braking pressure applied to the at least one wheel, the sensor comprising,
 - a plunger configured to receive the applied braking force, wherein the lower surface of the plunger has a ring-shaped first groove;
 - a disc-shaped membrane having an upper surface and lower surface, wherein the membrane is flexible according to the applied braking force received by the plunger,

wherein the upper surface of the membrane has a ring-shaped first bump, the first bump configured to complementarily fit into the first groove on the lower surface of the plunger, and

wherein the lower surface of the membrane has a ring-shaped second bump;

a sensing means centrally disposed on the membrane, wherein the sensing means measures the applied braking force when being bent or compressed caused by the membrane;

a support plate having a ring-shaped second groove that is configured so that the second bump on the lower surface of the membrane can complementarily fit into; and

whereby the applied braking force received by the plunger is transmitted to the membrane, causing the membrane to flex, which in turn causes the bending or compressing of the sensing means, resulting in the measurement of the applied braking force; and

a control unit electrically coupled to the braking device to control the braking pressure on the at least one wheel, wherein the control unit is configured to receive the measurement of the applied braking force from the braking device, and to process the measurement of the applied braking force to control the braking pressure on the at least one wheel.

11. The braking system according to claim 10, wherein the braking device applies the braking pressure on a disc mounted on the at least one wheel.

12. The braking system according to claim 11, wherein the braking device further comprises a plurality of brake pads for applying the braking pressure on the at least one wheel.

13. The braking system according to claim 12, wherein the braking device further comprises a plurality of electric motors coupled to the plurality of brake pads, wherein the a plurality of electric motors drive the plurality of brake pads to apply the braking pressure on the at least one wheel.

14. The braking system according to claim 13, wherein the plurality of electric motors are coupled to the plurality of brake pads via reduction gear, the reduction gear configured to transform the rotational motion of the plurality of electric motors to the translation motion of the plurality of brake pads, thereby causing the plurality of brake pads to apply the braking pressure on the at least one wheel
15. The braking system according to claim 14, wherein the reduction gear is coupled to the plunger of the sensor to enable the sensor to measure the braking pressure applied to the at least one wheel.
16. The braking system of claim 10, wherein the sensing means is coupled to the control unit.
17. The braking system according to claim 10, wherein the membrane of the sensor further comprises a convex step centrally disposed on the lower surface, wherein the convex step secures the sensing means between the lower surface of the membrane and the support plate.
18. The braking system according to claim 17, wherein the support plate of the sensor further comprises a depression configured for supporting the silicon die.
19. The braking system according to claim 17, wherein the ring-shaped second bump has at least one gap, wherein the at least one gap provides passage for an electrical connector to couple the silicon die to other electronic components.
20. The braking system according to claim 10, wherein the sensing means is centrally mounted on the upper surface of the membrane.

21. The braking system according to claim 10, wherein the sensing means is centrally mounted on the lower surface of the membrane.
22. The braking system according to claim 10, wherein the ring-shaped first bump has a smaller diameter than the ring-shaped second bump.
23. The braking system according to claim 10, wherein the ring-shaped first bump has a larger diameter than the ring-shaped second bump.
24. The braking system according to claim 10, wherein the sensing means is a silicon die with a plurality of integrated piezo-resistors, wherein the plurality of integrated piezo-resistors varies their resistance when bent or compressed.