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(54) VIBRATION DAMPING SYSTEM FOR DRILLING EQUIPMENT

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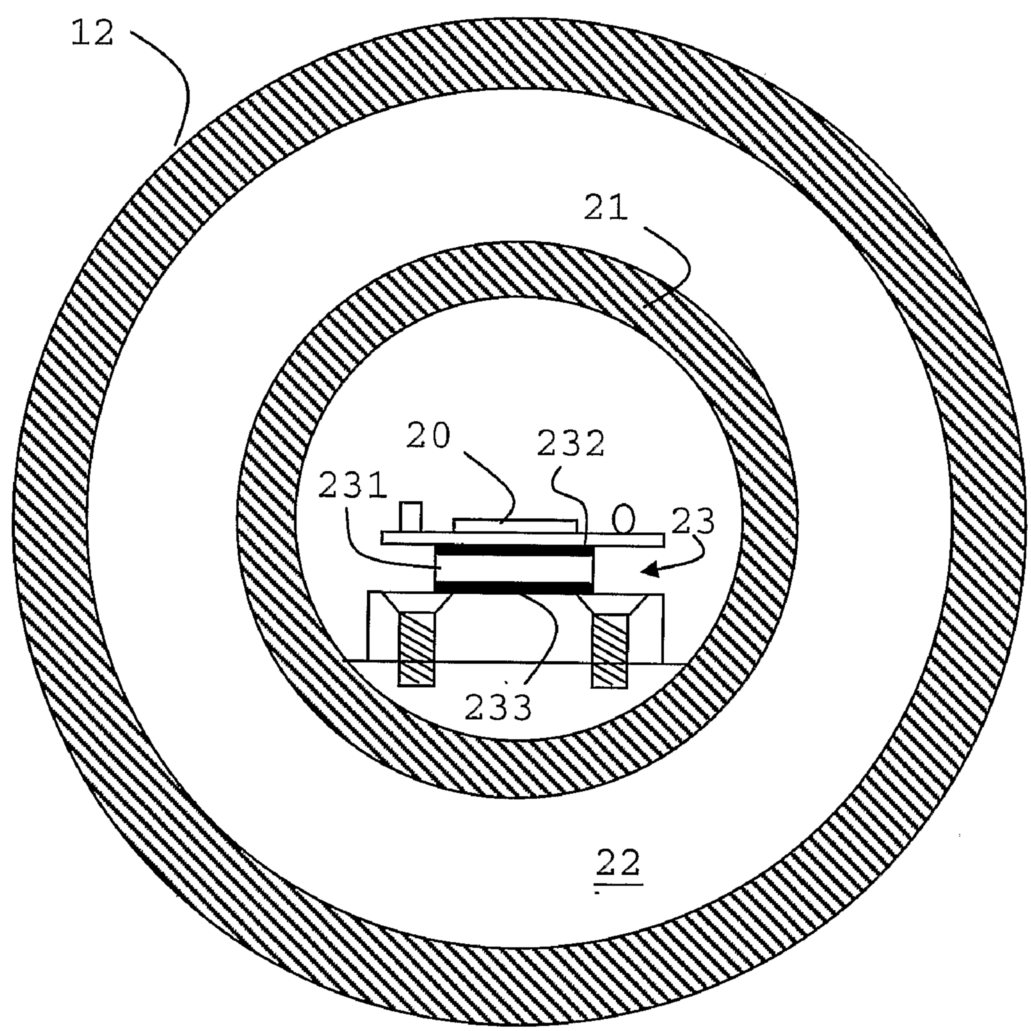
(57) **ABSTRACT**

A downhole tool is described designed to be suspended from a surface location into a wellbore (**11**), the tool including at least one module (**20**) with elements susceptible to mechanical vibrations or shocks, having the module coupled to remaining parts of the tool with one or more transducers (**31**) comprising electroactive polymeric material.



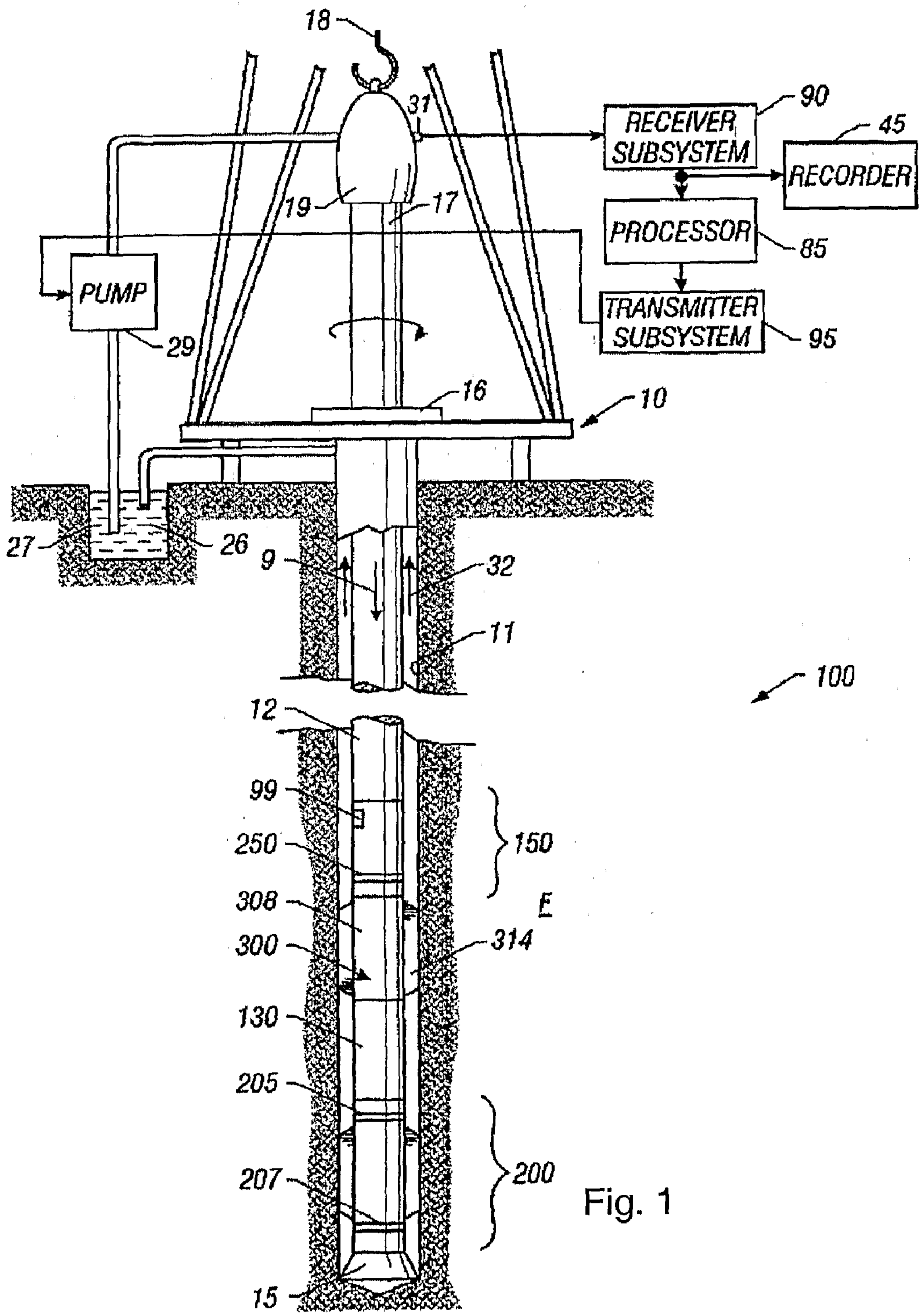

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Fig. 1

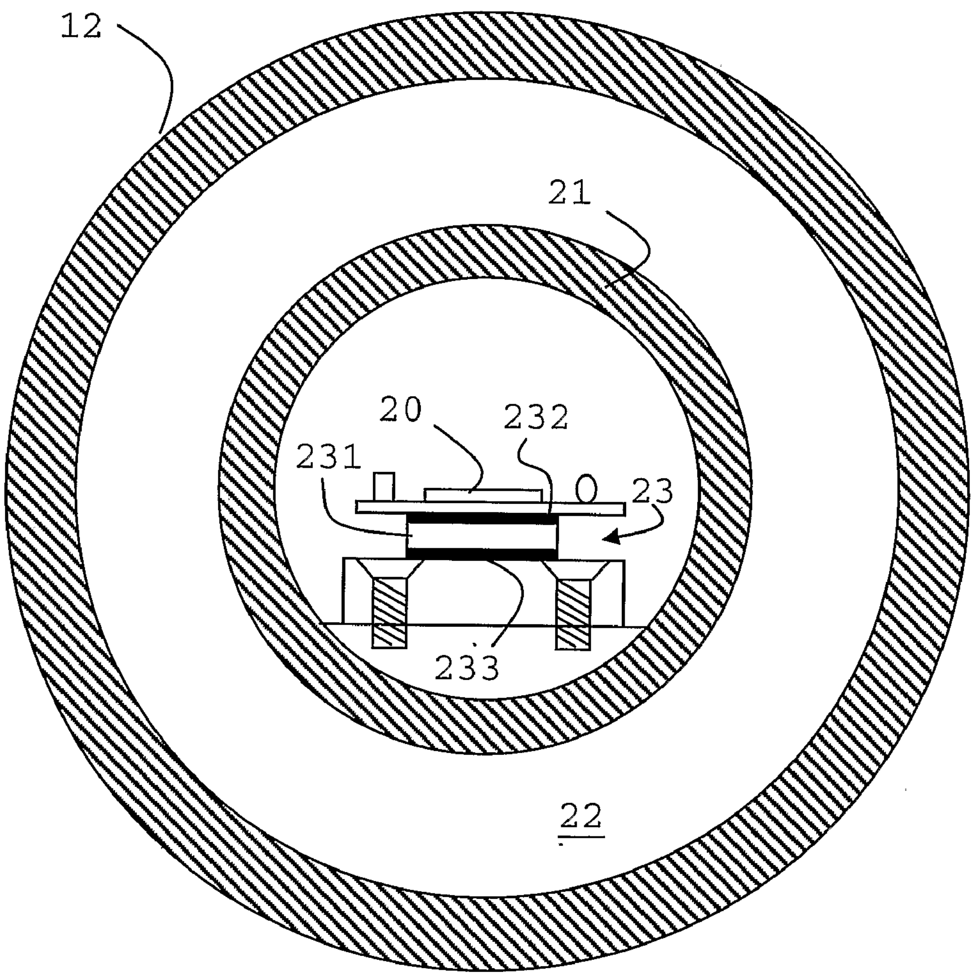

FIG. 2

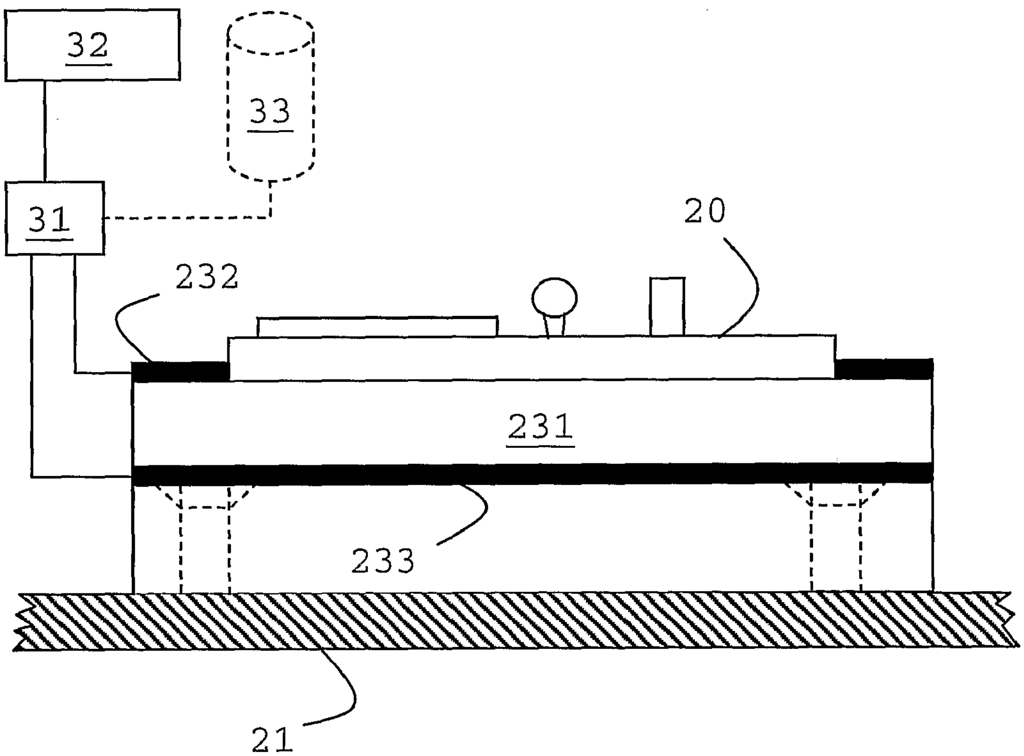

FIG. 3

VIBRATION DAMPING SYSTEM FOR DRILLING EQUIPMENT

[0001] The present invention generally relates to an apparatus and a method for vibration damping to damp vibrations produced when drilling a well. More specifically, it pertains to such an apparatus and method for protecting sensitive components, particularly electronic components, from shocks and vibrations generated while drilling.

BACKGROUND OF THE INVENTION

[0002] Various well logging and monitoring techniques are known in the field of hydrocarbon and water exploration and production and CO2 sequestration. These techniques employ downhole tools or instruments equipped for example with sources adapted to emit energy through a borehole traversing the subsurface formation. The emitted energy passes through the borehole fluid ("mud") and into the surrounding formations to produce signals that are detected and measured by one or more sensors, which typically are also disposed on the downhole tools. By processing the detected signal data, a profile of the formation properties is obtained.

[0003] A downhole tool, comprising a number of emitting sources and sensors for measuring various parameters, may be lowered into a borehole on the end of a cable, a wireline, a drill string or coiled tubing.

[0004] Based on the collection of data on downhole conditions during the drilling process, the driller can modify or correct key steps of the operation to optimize performance. Schemes for collecting data of downhole conditions and movement of the drilling assembly during the drilling operation are known as Measurement While Drilling (MWD) techniques. Similar techniques focusing more on measurement of formation parameters than on movement of the drilling assembly are known as Logging While Drilling (LWD). Here, the operator can make or revise decisions concerning the drilling and production of the well.

[0005] These tools are typically equipped with sensitive components, e.g., electronics packages, boards and modules, that often are not designed for such harsh environments. The trend among manufacturers of electronic components is to address the high-volume commercial market, making it difficult to find components for downhole tools that function effectively at high levels of vibrations and mechanical shocks.

[0006] The vibrations are typically caused by drilling activity. Drilling involves an axial load to the drill bit when the bit is in contact with the formation at the bottom of the wellbore, while rotating the bit. The vibrations have damaging effects on electronic instrumentation present in the MWD and LWD tools.

[0007] Many efforts have been made to design mechanical devices to reduce oscillations, shocks, and vibrations. Some of the devices use reciprocating mandrels in combination with a compressible fluid filled chamber to absorb shocks and dampen vibrations, such as the device disclosed in U.S. Pat. No. 4,439,167 issued to Bishop et. al.

[0008] Other devices use a plurality of resilient elastomer elements or belleville springs to absorb axial shocks, such as the floating sub disclosed in U.S. Pat. No. 4,844,181 issued to Bassinger.

[0009] Another class of devices uses floating pistons and compressible fluid filled chambers to absorb axial vibrations, such as the device disclosed in U.S. Pat. No. 4,901,806 issued to Forrest. Another class of devices uses a helically splined mandrel or annular springs to absorb vibrations, such as the drill string shock absorber disclosed in U.S. Pat. No. 3,947,008 issued to Mullins.

[0010] U.S. Pat. No. 3,265,091 issued to De Jarnett discloses another device for absorbing vibrations that includes a drill pipe having an inner steel tube and an outer steel tube. The annular space between the tubes is filled with a fluid of preselected density that acts to damp or absorb vibrations. Similarly in the published European patent application EP-0414334 there is disclosed a shock absorber with a fluid chamber, in which a piston slides. The chamber has at least two openings diminishing hole area through which the fluid can escape from the chamber.

[0011] U.S. Pat. No. 6,364,039 B1 issued to Majkovic discloses a vibration damping apparatus including an annular housing, a cavity between an internal diameter and an external diameter of the housing, and a substantially solid vibration damping material disposed in the cavity. The vibration damping material has a density that is greater than the density of the housing material.

[0012] In view of the above art it is an object of the invention to provide a simple, robust and versatile apparatus and method for protecting sensitive components such as electronic boards or circuitry from exposure to vibrations and shocks in a downhole environment, particularly while drilling.

SUMMARY OF THE INVENTION

[0013] In accordance with a first aspect of the invention, there is provided a downhole tool designed to be suspended from a surface location into a wellbore, said tool including at least one module with elements susceptible to mechanical vibrations or shocks, wherein said module is coupled to remaining parts of the tool with one or more transducers comprising electroactive polymeric material.

[0014] In accordance with a second aspect of the invention, there is provided a method for reducing the effects of accelerations on a module within a downhole tool, comprising the step of coupling said module to remaining parts of the tool with one or more transducers comprising electroactive polymeric material; and lowering said tool into a subterranean wellbore.

[0015] In a preferred embodiment of the invention, the state of the electroactive polymeric material is changed depending on the intensity and/or direction of the accelerations or vibrations, which are preferably registered using suitable sensors, such as accelerometers.

[0016] In another preferred embodiment the use of the electroactive polymeric material is reversed to act as a harvesting tool to convert the vibrations into electric energy. This energy suitably accumulated and stored can be used for example to provide the power for the purpose of damping.

[0017] These and other aspects of the invention will be apparent from the following detailed description of non-limitative examples and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** illustrates an example of a LWD scenario, in which the present invention can be used;

[0019] FIG. **2** shows details of the LWD tool of FIG. **1** including an example of the invention; and

[0020] FIG. **3** is a schematic isolated view of an electronic boards protected using an example of the invention.

DETAILED DESCRIPTION

[0021] FIG. **1** illustrates a conventional drilling rig and drill string in which the present invention can be utilized to advantage. A land-based platform and derrick assembly **10** is positioned over a wellbore **11** penetrating a subsurface formation F. In the illustrated embodiment, the wellbore **11** is formed by rotary drilling in a manner that is well known. Those of ordinary skill in the art given the benefit of this disclosure will appreciate, however, that the present invention also finds application in directional drilling applications as well as rotary drilling, and is not limited to land-based rigs, but can be equally applied to off-shore drilling.

[0022] A drill string **12** is suspended within the wellbore **11** and includes a drill bit **15** at its lower end.

[0023] The drill string **12** is rotated by a rotary table **16**, energized by means not shown, which engages a kelly **17** at the upper end of the drill string. The drill string **12** is suspended from a hook **18**, attached to a traveling block (also not shown), through the kelly **17** and a rotary swivel **19** which permits rotation of the drill string relative to the hook.

[0024] Drilling fluid or mud **26** is stored in a pit **27** formed at the well site. A pump **29** delivers the drilling fluid **26** to the interior of the drill string **12** via a port in the swivel **19**, inducing the drilling fluid to flow downwardly through the drill string **12** as indicated by a directional arrow **9**. The drilling fluid exits the drill string **12** via ports in the drill bit **15**, and then circulates upwardly through the region between the outside of the drillstring and the wall of the wellbore, called the annulus, as indicated by the direction arrows **32**. In this manner, the drilling fluid lubricates drill bit **15** and carries formation cuttings up to the surface as it is returned to pit **27** for recirculation.

[0025] Drillstring **12** further includes a bottom hole assembly, generally referred to as **100**, near the drill bit **15** (or in technical terms, within several drill collar lengths from the drill bit). The bottom hole assembly includes capabilities for measuring, processing, and storing information, as well as communicating with the surface.

[0026] The bottom hole assembly **100** thus includes, among other things, measuring and local communications apparatus **200** for determining and communicating while drilling wellbore or formation parameters such as for example the resistivity of the formation F surrounding the wellbore **11**. An example of apparatus **200**, including transmitting antenna **205** and receiving antenna **207**, is described in detail in U.S. Pat. No. 5,339,037, commonly assigned to the assignee of the present application, the entire contents of which are incorporated herein by reference.

[0027] The assembly **100** further includes a drill collar **130** for performing various other measurement functions, and surface/local communications subassembly **150**. Subassembly **150** includes toroidal antenna **250** used for local communication with apparatus **200**, and a known type of acoustic communication system that communicates with a similar system (not shown) at the earth's surface via signals carried in the drilling fluid or mud. Thus, the surface communication system in subassembly **150** includes an acoustic transmitter which generates an acoustic signal in the drilling fluid that is representative of measured downhole parameters.

[0028] One suitable type of acoustic transmitter employs a device known as a "mud siren" which includes a slotted stator and a slotted rotor that rotate and repeatedly interrupt the flow of drilling fluid to establish a desired acoustical wave signal in the drilling fluid. The driving electronics in subassembly **150** may include a suitable modulator, such as a phase shift keying (PSK) modulator, which conventionally produces driving signals for application to the mud transmitter. These driving signals can be used to apply appropriate modulation to the mud siren. Again the electronic elements of the mud pulse telemetry system requires protection from the impact of vibrations and shocks and, hence, can be protected using the present invention.

[0029] The generated acoustical wave is received at the surface by transducers represented by reference numeral **31**. The transducers, for example, piezoelectric transducers, convert the received acoustical signals to electronic signals. The output of transducers **31** is coupled to uphole receiving subsystem **90**, which demodulates the transmitted signals. The output of receiving subsystem **90** is then couple to processor **85** and recorder **45**.

[0030] Drill string **12** is further equipped in the embodiment of FIG. **1** with stabilizer collar **300**.

[0031] Uphole transmitting system **95** is also provided, and is operative to control interruption of the operation of pump **29** in a manner that is detectable by transducers **99** in subassembly **150**. In this manner, there is two-way communication between subassembly **150** and the uphole equipment. Subassembly **150** is described in greater detail in U.S. Pat. No. 5,235,285, the entire contents of which are also incorporated herein by reference. Those skilled in the art will appreciate that alternative acoustic, as well as other techniques, can be employed for communication with the surface.

[0032] The power for all electrical systems including above mentioned elements and the electronic components and sensors which from part of an example of invention as discussed below, is supplied as the turbine alternator or positive displacement motor driven by the drilling mud, such as a Moineau-type motor (not shown). In other embodiments (not shown), power could be supplied by any power supply apparatus including an energy storage device located downhole, such as a battery, or even supplied by wire or pressure pulses from the surface.

[0033] However, it should be noted that for the purpose of the present invention the exact purpose and components of the measuring and communication apparatus **200** or instrumentation of the bottom hole assembly **100** are not essential. Such apparatus can include any configuration or module including transistors, integrated circuits, resistors, capacitors, and inductors, as well as electronic components such as sensing elements, including antennae, accelerometers, magnetometers, photomultiplier tubes, sampling probes, pressure and strain gages, timers, optical elements and the like. And in the following an electric board is used to exemplify the above or other similar devices.

[0034] As shown in FIG. **2**, an electronic module **20** for LWD applications is typically located inside a protective cylindrical housing **21**, which is preferably formed from stainless steel or a beryllium copper alloy. The housing **21** is either part of or enclosed within the drill string **12** as illustrated above. Depending on the specific embodiment a passage for the flow of drilling mud is present either as shown in form of an annular passage **22** formed between the outer surface of the housing **21** and the inner surface of the drill pipe **12** or (not shown) as a channel through the center of the drill string.

[0035] In the example the drilling mud flows through the annular passage **22** on its way to the drill bit **15**, as previously discussed.

[0036] The electronic component **20** may, but according to the invention does not necessarily, include one or more printed circuit boards associated with the sensing device, as previously discussed. The module **20** can for example be the control module, power regulator module, or pulsar module, or a sensor module etc. in which case the electronic component may differ in a way immaterial to the invention.

[0037] As shown in FIG. **2**, the module **20** is at least partly mounted on a damping element **23** that includes an electroactive polymer (EAP) **231**. The polymer is shown between two layers **232**, **233** of an electrically conducting material.

[0038] To illustrate the operating principle of the invention, a schematic diagram of the above module is shown in FIG. **3** isolated from the surrounding housing **21**.

[0039] In FIG. **3** there is shown the module **20**, mounted onto the top layer **232** of conducting material. The space between the two layers **232**, **233** is filled with electroactive polymer material **231**, possible composition of which are described below. The three layers **231**-**233** form effectively a capacitor-type configuration, however, when applying a voltage between the two layers **232**, **233**, the EAP layer **231** deforms or changes its properties, e.g. from a stiff to a elastic state. The configuration can hence also be regarded as being a transducer.

[0040] The deformation or state transition translates into either an acceleration of the mounted module **20** or a change in the stiffness with which the module **20** is coupled to the housing **21**. Hence, by controlling the voltage supplied to the layers **232**, **233** and thus the deformation or state of the EAP, the module can be accelerated into any direction as defined by the design and location of the EAP material or, alternatively, coupled to its housing with a controllable stiffness.

[0041] The invention exploits the changeable properties of the EAP material by registering shocks and vibrations using one or a plurality of shock sensors **31** which are part of the downhole tool. The sensors **31** can for example be conventional accelerometers.

[0042] The shock sensors are used to drive directly or via a control loop a power source **32**, which in turn alters the state of the EAP material at the appropriate times to reduce the effect of any registered acceleration, vibration or other mechanical shock. In the present example, the power source **32** is connected to the downhole generator which supplies power to all components of the downhole tool.

[0043] It should be noted however that by reversing the above process, electrical power can actually be generated using the deformation of the EAP material to harvest electrical energy through the conversion of the mechanical movement of the module **20** relative to the housing. Using for example a charging circuit and a battery or a storage capacitor **33** the apparatus of FIGS. **2** and **3** can be used to generate and store electric power.

[0044] By accumulating for example electric energy from low impact vibrations and releasing the stored power to dampen potentially harmful vibrations, the system can be designed to operate quasi-autarkic.

[0045] A wide class of EAP materials are commercially available.

[0046] Generally, EAP can be divided into two major groups based on their activation mechanism including: ionic (involving mobility or diffusion of ions) and electronic (driven by electric field). A list of the leading EAP materials is given in Table 1 below.

TABLE 1

List of the EAP materials

Electronic EAP	Ionic EAP
Dielectric EAP	Carbon Nanotubes (CNT)
Electrostrictive Graft Elastomers	Conductive Polymers (CP)
Electrostrictive Paper	ElectroRheological Fluids (ERF)
Electro-Viscoelastic Elastomers	Ionic Polymer Gels (IPG)
Ferroelectric Polymers	Ionic Polymer Metallic Composite (IPMC)

[0047] The electronic polymers (electrostrictive, electrostatic, piezoelectric, and ferroelectric) are driven by electric fields and can be made to hold the induced displacement under activation of a dc voltage, allowing them to be considered for robotic applications. Also, these materials have a greater mechanical energy density and they can be operated in air with no major constraints. However, they require a high activation field (>100 MV/meter) close to the breakdown level.

[0048] In contrast, ionic EAP materials (gels, polymer-metal composites, conductive polymers, and carbon nanotubes.) are driven by diffusion of ions and they require an electrolyte for the actuation mechanism. Their major advantage is the requirement for drive voltages as low as 1 to 2 volts. However, there is a need to maintain their wetness, and except for conductive polymers and carbon nanotubes it is difficult to sustain dc-induced displacements. The induced displacement of both the electronic and ionic EAP can be geometrically designed to bend, stretch, or contract. Any of the existing EAP materials can be made to bend with a significant curving response, offering actuators with an easy to see reaction and an appealing response.

[0049] A particularly suitable EAP material is known for example from the U.S. Pat. No. 6,543,110 issued to Pelrine et al. and related patents and patent applications as cited therein.

[0050] This particular material is known as pre-strained electroactive polymers. When a voltage is applied to electrodes contacting a pre-strained polymer, the polymer deflects. This deflection may be used to do mechanical work. The pre-strain improves the mechanical response of an electroactive polymer. The above referenced patent also describes the details of manufacturing compliant electrodes that conform to the shape of a polymer and electromechanical devices.

[0051] Materials suitable for use as a pre-strained polymer with the present invention may include any substantially insulating polymer or rubber that deforms in response to an electrostatic force or whose deformation results in a change in electric field. One suitable material is NuSil CF19-2186 as provided by NuSil Technology of Carpenteria, Calif. Other exemplary materials suitable for use as a pre-strained polymer include, any dielectric elastomeric polymer, silicone rubbers, fluoroelastomers, silicones such as Dow Corning HS3 as provided by Dow Corning of Wilmington, Del., fluorosilicones such as Dow Corning 730 as provided by Dow Corning of Wilmington, Del., etc, and acrylic polymers such as any acrylic in the 4900 VHB acrylic series as provided by 3M Corp. of St. Paul, Minn.

[0052] In many cases, materials used in accordance with the present invention are commercially available polymers.

The commercially available polymers may include, for example, any commercially available silicone elastomer, polyurethane, PVDF copolymer and adhesive elastomer. Using commercially available materials provides cost-effective alternatives for transducers and associated devices of the present invention. The use of commercially available materials may simplify fabrication. In one embodiment, the commercially available polymer is a commercially available acrylic elastomer comprising mixtures of aliphatic acrylate that are photocured during fabrication. The elasticity of the acrylic elastomer results from a combination of the branched aliphatic groups and crosslinking between the acrylic polymer chains.

[0053] While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the spirit and scope of the invention.

1. A downhole tool designed to be suspended from a surface location into a wellbore, said tool including at least one module with elements susceptible to mechanical vibrations or shocks, wherein said module is coupled to remaining parts of the tool with one or more transducers comprising electroactive polymeric material.

2. The tool of claim **1**, being a logging-while-drilling or measurement-while-drilling tool.

3. The tool of claim **1**, wherein the module comprises an electronic board or circuits.

4. The tool of claim **1**, wherein electroactive polymeric material changes its state depending on the intensity and/or direction of the vibrations or shock.

5. The tool of claim **4**, further comprising a control circuit to control a state of the electroactive polymeric material.

6. The tool of claim **5**, wherein the control circuit includes one or more vibration sensors.

7. The tool of claim **5**, wherein the control circuit is programmed to apply a voltage or current to the electroactive polymeric material.

8. The tool of claim **1**, including a circuit to convert deformation of the electroactive polymeric material into electrical energy and store said electric energy.

9. The tool of claim **8**, further comprising a control circuit to use the stored energy to drive the one or more transducers.

10. A method for reducing the effects of accelerations on a module within a downhole tool, comprising the step of coupling said module to remaining parts of the tool with one or more transducers comprising electroactive polymeric material; and lowering said tool into a subterranean wellbore.

11. The method of claim **10**, further comprising the step of changing the state of the electroactive polymeric material depending on the intensity and/or direction of the accelerations.

12. The method of claim **11**, further comprising the step of controlling the current or voltage applied to the electroactive polymeric material in dependence of tool accelerations as measured by sensors.

13. The method of claim **10**, wherein deformation of the electroactive polymeric material is used to harvest energy from the mechanical vibrations.

14. The method of claim **13**, wherein at least part of the energy required to activate the one or more transducers is obtained by the harvesting from mechanical vibrations.

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