An Economical Lightweight Field Deployable PiezoElectric Gravimeter (PEG)

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ABSTRACT

The piezoelectric stimulus-response quantification based gravimeter (PEG) functions entirely different from conventional gravimeters. This innovative technology's method of operation is achieved by economically utilizing shear type piezoelectric transducers with a novel approach to piezoelectric instrumentation. The piezoelectric transducers are provided with excitation energy (stimulus), causing a highly reproducible response across a full frequency spectrum. This allows the piezoelectric transducer to take static as well as dynamic measurements as opposed to the conventional utilization of piezoelectric devices that require a dynamically changing quantity. The gravimeter is capable of measuring an abundant amount of other physical quantities such as thermal, magnetic, electrical, electromotive, electromagnetic, and electro-static fields. Resultant characteristics are automatically quantified and compensated through vector analyses and data reduction algorithms.

Keywords: piezoelectric, gravimeter, transducer, measurements, instrumentation, magnetic, electrical, electromotive, electromagnetic, electro-static, compensated

1 BACKGROUND

The sensing of an environment's or structure's state is important and often critical in a wide variety of applications. Sensors and sensing systems are typically specifically-designed for their particular function. This leads to a time-consuming and costly cycle of "design, test, and build" since there is no real standard-sensor building block that can be adapted to sense a variety of attributes and physical states. Accordingly, the objective ofthe developed technology to provide a sensing system and method that can serve as the building block for a wide variety of attribute sensing applications. The technology is embedded into a sensing system and method currently known as the "PiezoElectric stimulus-response quantification based Gravimeter (PEG)" (Figure 1). The technology relates to more than gravitational measurementation, and it is more accurately defined as a field disturbance sensor system and method using one or more piezoelectric elements. The PEG is readily adapted to be sensitive to disturbances in a wide variety of localized energy fields.

Figure 1: The Piezoelectric Gravimeter (PEG1)

2 INTRODUCTION

The piezoelectric field disturbance sensing system includes a piezoelectric element for generating mechanical energy when electrically excited and for generating electrical energy when mechanically deformed. A mass is coupled to the piezoelectric element for interaction with energy fields. A signal generator is also coupled to the piezoelectric element for applying electrical energy at a fixed period of time wherein the piezoelectric element undergoes mechanical deformation. This makes the mass reverberate mechanical energy in response to the mechanical deformation similar to ringing a bell. A charge monitor is coupled to the piezoelectric element for subsequently collecting the reverberating energy in the attached mass. Local energy fields change the way the reverberating energy occurs and the difference is quantifiable. The method of operating can serve as the building block for a wide variety of sensing applications such as the sensing and monitoring of gravitational fields, vibrations, magnetic fields, electric fields, electromotive fields, electromagnetic fields, electro-static fields, radio frequency fields, and thermal gradients. While the basic structure of the technologies sensing systems and method remains the same for each application. Gravity fields were identified as an excellent area of detection to target while developing the technology into a practical and manufacturable device. Gravitational forces have a dampening effect on any mechanical energy imparted into the mass of the sensor, and the sensitivity of the system to the surrounding gravitational forces can be correspondingly tuned. Different types of piezoelectric elements and mass

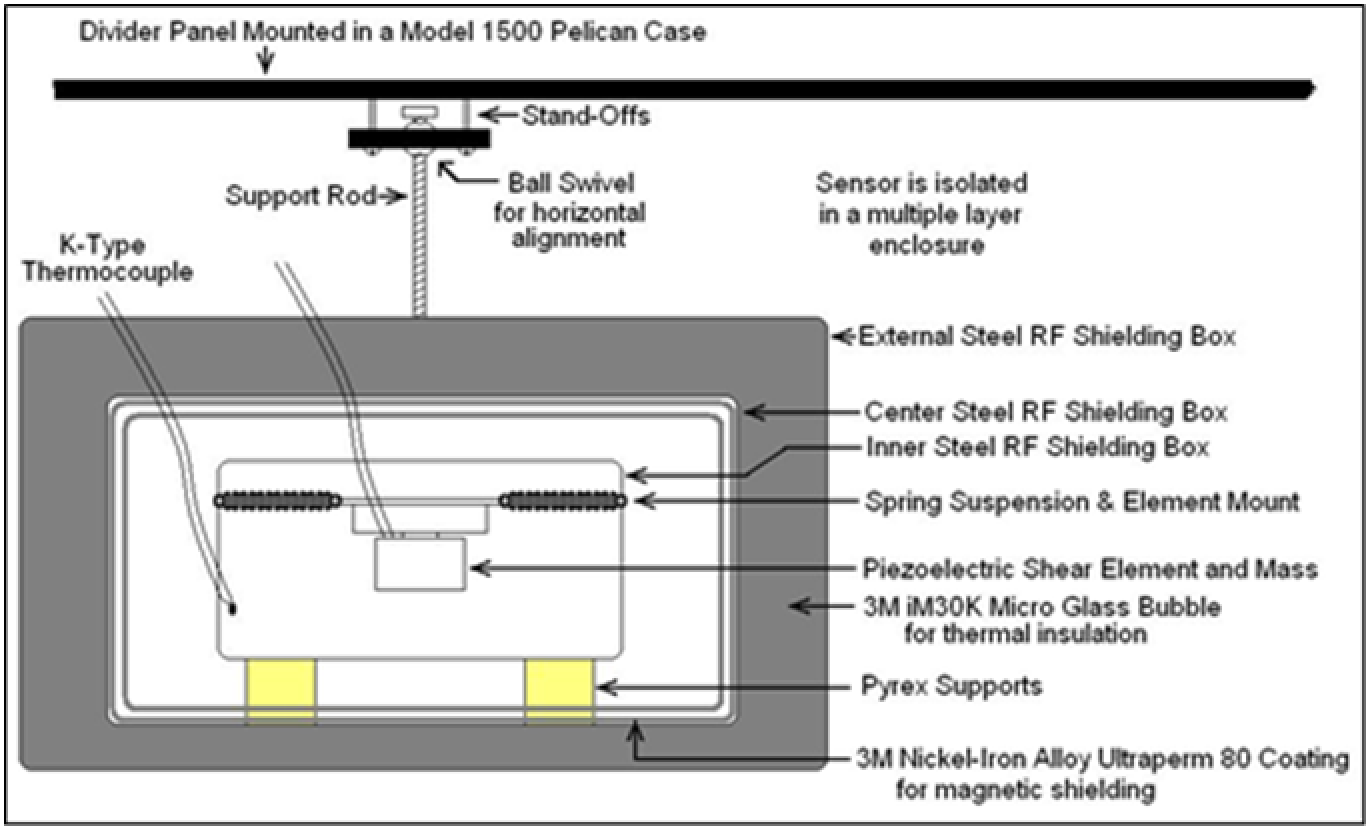

Figure 2: The piezoelectric sensor's multiple layer enclosure

structures can be used in order to satisfy sensitivity and/or ruggedness as required.

In order to prevent or desensitize the piezoelectric element relative to unwanted stimulation, it may be necessary to provide shielding and/or isolation structures. A wide range of configurations, materials, and construction methods can be employed for shielding/desensitizing without effecting the desired performance or sensitivity. The PEG multi-layer shielding and enclosure can also be completely omitted to reduce weight within an environment that has little external stimuli (Figure 2). In this way, the sensor technology can be designed for incorporation within a satellite where size and weight is critical. Additionally, a unit's electronics could be condensed into a MEMS circuit with an integrated microprocessor to reduce a unit's overall size. Another notable application for the technology is security. The sensing system can be incorporated into a security system to detect the removal of a protected object's mass, wherein all the vibrational damping devices are removed to help detect intrusion within a restricted area. The technology can also be used to quantify other physical conditions such as vacuum levels and liquid detection by physically coupling the sensing system to a structure under test. For example, the sensing system could be used to detect the loss of a vacuum within a vacuum jacketed pipe without tapping into the piping by interchanging the sensing system's enclosure with a bondable base. The bondable base could be fastened to any location on the outside of a jacketed pipe and the sensing system would then be capable of quantifying a change to the internal vacuum levels. The different vacuum levels will dampen how the bonded sensing system will vibrate during the stimulus/response cycle thereby revealing the vacuum levels similar to the way gravity dampens the sensing system's reverberations. In the same way, the technology could be used to detect the presence of liquid or the lack of liquid within a pipeline. For example, the presence of liquid nitrogen within a gaseous nitrogen supply line could be detected by simply bonding the sensing system and its enclosure to the outside of the pipe without exposing the sensor elements or electronics to the internal cryogenic conditions. The same would be true for detecting the formation of gas within a liquid nitrogen pipe as it can become hot enough to allow some of the liquid to change states into gaseous nitrogen. Both of these examples provide instances where monitoring is very important, and the current state of other sensory technologies makes this kind of detection difficult.

The advantages of the developed technology are numerous. The sensing system can be configured to monitor/measure multiple types of static quantities such as gravity, static electricity, electrically charged fields, temperature, and magnetic fields. The support for the sensing system can be designed to desensitize the sensing system to a variety of unwanted external stimuli thereby limiting sensitivity of the sensing system to one or more

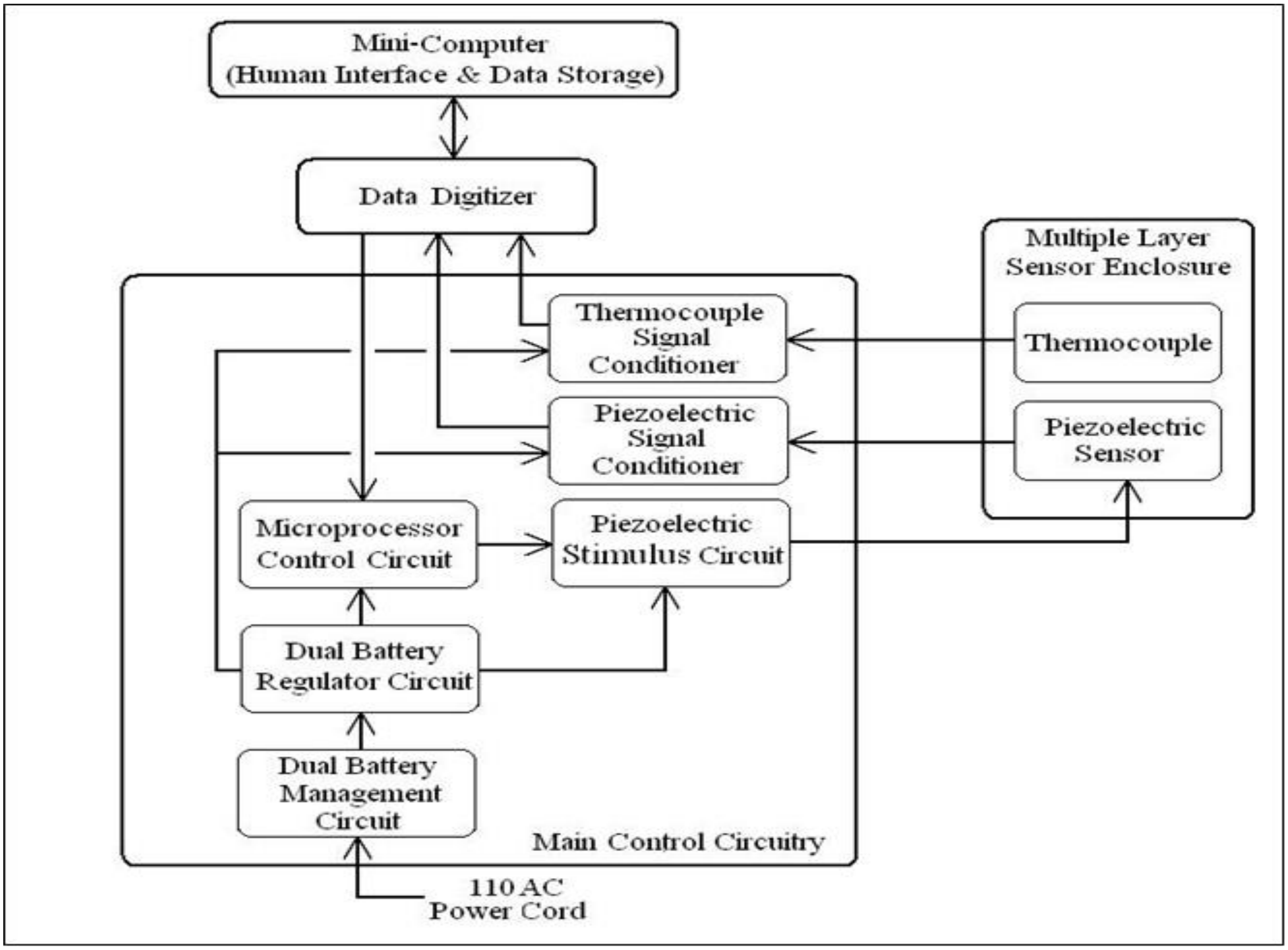

Figure 3: Main Circuitry Block Diagram

stimuli of interest. Although the technology has been described relative to gravitational detection, there are numerous variations and modifications that can be achieved for a wide range of applications.

2 SUMMARY

Conventional gravimeters typically measure the amount of the opposing forces required to suspend an object or by monitoring an objects freefall rate. This innovative technology uses piezoelectric instrumentation in a completely new way, reversing their role. The piezoelectric transducers are provided with excitation energy, causing a highly reproducible response across a full frequency spectrum. This is known as the piezoelectric stimulus-response effect. This allows the piezoelectric transducer to take static measurements opposed to the conventional utilization of piezoelectric devices that require a dynamically changing quantity.

This gravimeter is capable of measuring numerous types of physical quantities such as thermal, magnetic, and static forces. When the pull of gravity is introduced, the original element characteristics are immediately changed along with the fluctuations in gravity. These types of transducers are specifically designed to maximize the gravitational effects of the elements vibratory characteristics. The resultant characteristics are automatically quantified and temperature compensated through vector analyses and data reduction algorithms into gravitational units. This stimulus-response process is highly repeatable, which produces a near exact response or measurement from each collected reading—completely revolutionizing the precision and accuracy.The gravimeter is capable of measuring numerous other types physical quantities such as thermal, magnetic, electrical, electromotive, electromagnetic, and electro-static fields; and provide structural information.

REFERENCES

[1] PiezoElectric Gravimeter Provisional Application for Patent (Serial # 61/982,474), submitted 5/15/2014.

[2] Jensen, S., In Situ Health Monitoring of Piezoelectric Sensors, US Patent 8,401,820 B2, awarded March 19, 2013.