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(54) **MONITORING SYSTEM AND METHOD**

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Related U.S. Application Data

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(51) **Int. Cl.**^{7} **G08B 21/00**

(52) **U.S. Cl.** **340/665**; 340/666; 340/667; 73/760; 73/862.045; 73/862.046

(58) **Field of Search** 340/665, 666, 340/667, 657, 658, 573.1; 73/760, 862.045, 862.046; 345/173, 174

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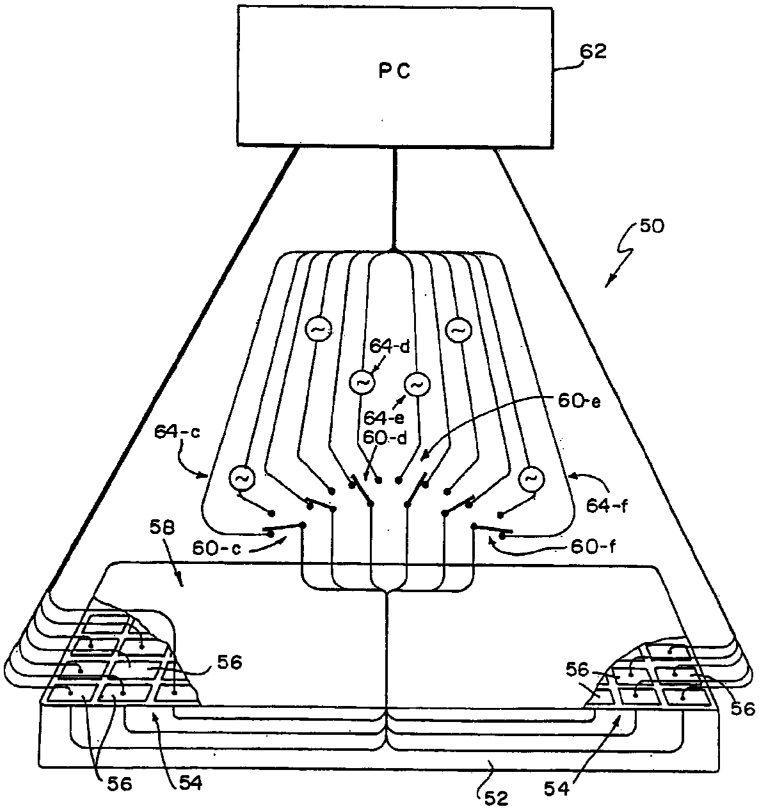
(57) **ABSTRACT**

A system including piezoelectric material wherein a force exerted on the piezoelectric material is determined by subjecting the piezoelectric material to an input signal of sweeping frequency and evaluating the response of the piezoelectric material to the applied signal.

77 Claims, 3 Drawing Sheets



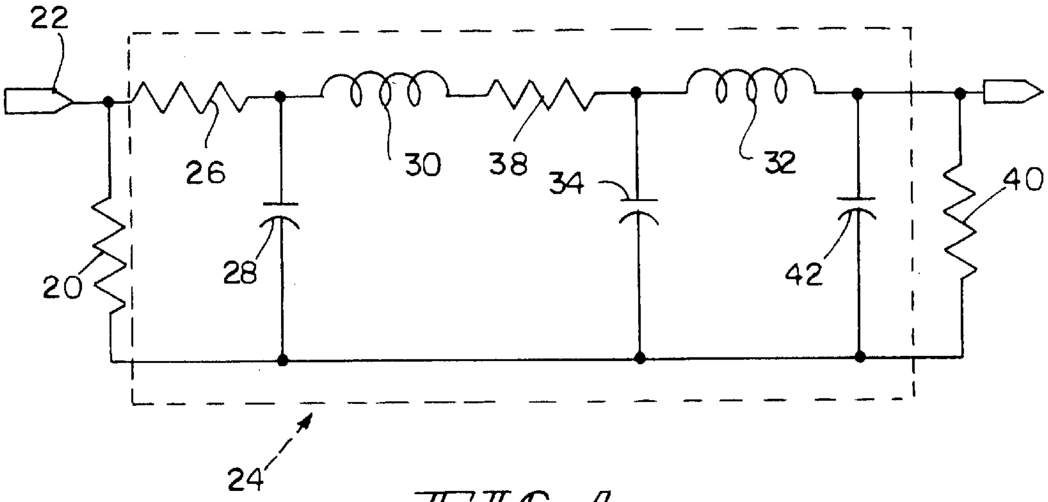
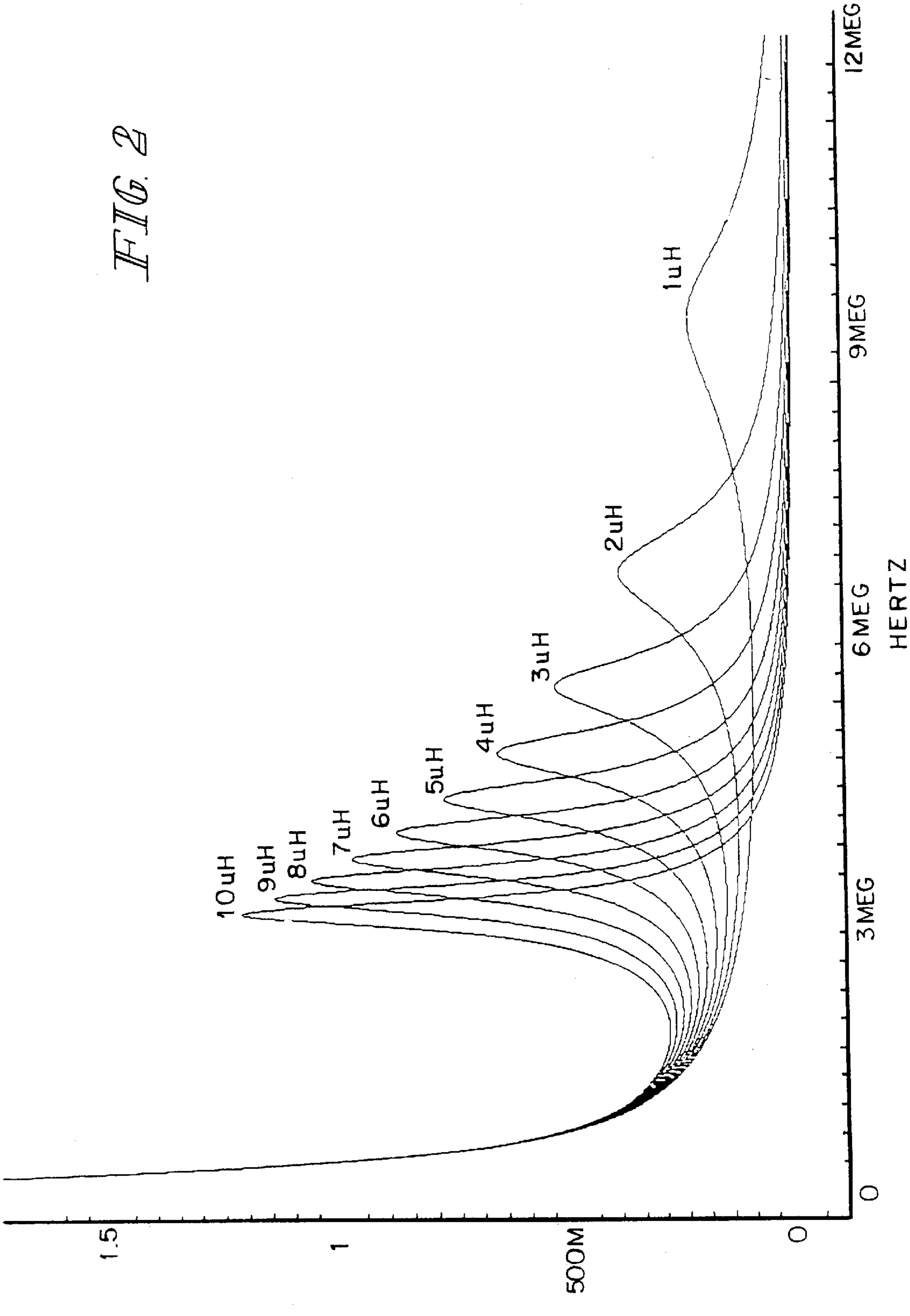


FIG 1

FIG. 2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0
3MEG
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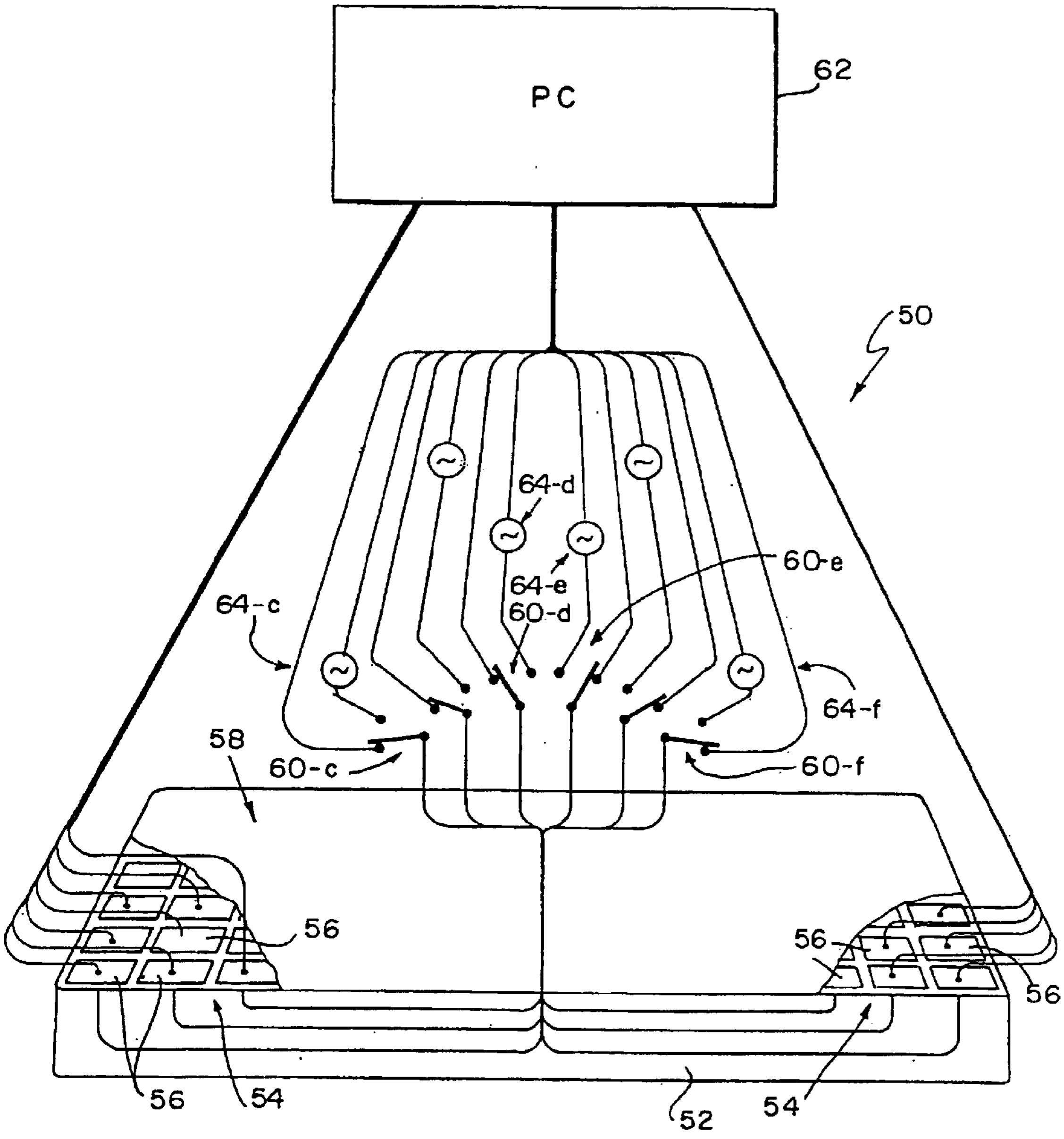

FIG. 3

MONITORING SYSTEM AND METHOD

[illegible]

This application is a continuation of U.S. application Ser. No. 09/263,038 filed Mar. 05, 1999, now U.S. Pat. No. 6,252,512.

BACKGROUND AND SUMMARY OF THE INVENTION

Piezoelectric materials are well know for their ability to generate an electrical output when they are placed under mechanical stress. The frequency and magnitude of an electric signal developed across such a piezoelectric material are directly proportional to the frequency and magnitude of a force applied to the material. There are characteristics of the piezoelectric material's mechanical system that are analogous to electrical systems. For example, the material's response to a mechanical force attempting to bend it is related to the mechanical force in much the same way an impedance is related to the electrical potential across the impedance. Piezoelectric materials can be characterized by their inductive, capacitive and resistive properties. There are numerous applications of piezoelectric materials' ability to generate electrical signals which vary with applied force. When the applied force is not changing, there is no output from the piezoelectric material.

Piezoelectric materials also undergo mechanical motion when electrical potentials are applied across them. There are several applications that make use of this characteristic for the purpose of changing electrical energy into mechanical energy. A piezoelectric material's ability to react to electrical energy can be used to detect the amount of an applied mechanical force. A piezoelectric device is coupled to a function generator capable of generating, for example, a sine wave of a desired frequency and amplitude. If no external force is applied to the piezoelectric material, the material will deflect back and forth at the same frequency and relative magnitude to the applied signal. If an external mechanical force is applied to the material when the electrical signal is applied, the mechanical force will tend to inhibit the electrically induced motion of the piezoelectric material. This resistance to motion will be reflected back to the electrical system as an impedance to current flow and the applied electrical energy not manifested as motion is dissipated as heat in the piezoelectric material. The source subsystem can be constructed in such a way as to detect this extra impedance, for example, by monitoring changes in current flow, or, in a constant current system, by changes in the voltage across the piezoelectric element. Either way, the force applied to the piezoelectric material is reflected back to the source of the applied electrical potential.

According to one aspect of the invention, a monitoring method comprises providing a first, piezoelectric device which is subject to a force to be monitored, determining the

[illegible]

providing a switch having a first state corresponding to a

[illegible]

applied to the first device is being substantially modulated and a second state corresponding to a static mode of operation when the force applied to the first device is not being substantially modulated.

Illustratively according to this aspect of the invention, switching of the switch to the second state causes a signal to be applied to the first device and causes the impedance of the first device to the applied signal to be determined.

Further illustratively according to this aspect of the invention, determining the first device's output and correlating the first device's output with the force comprise providing electrical signals for exciting the first device and determining the impedance of the first device to the electrical signals.

Additionally illustratively according to this aspect of the invention, providing electrical signals for exciting the first device and determining the impedance of the first device to the electrical signals comprise sweeping the signal frequency and determining the first device's impedance in response to the swept signal frequency.

Illustratively according to this aspect of the invention, determining the first device's output and correlating the first device's output with the force comprise determining from the impedance the force on the first device.

Illustratively according to this aspect of the invention, the method further comprises determining from the determined force whether an object is on the first device.

Additionally illustratively according to this aspect of the invention, providing a first device comprises providing a plurality of said first devices coupled together in an array.

Illustratively according to this aspect of the invention, providing a first, piezoelectric device comprises providing a flexible piezoelectric film.

Further illustratively according to this aspect of the invention, providing a flexible piezoelectric film comprises providing an array of said first devices.

Illustratively according to this aspect of the invention, providing a first device comprises providing a coaxial cable including a center conductor, a shield, and between the center conductor and shield, a piezoelectric material.

Further illustratively according to this aspect of the invention, providing a first device comprises providing a piezoelectric ceramic transducer.

Additionally illustratively according to this aspect of the invention, providing a plurality of said first devices coupled together in an array further comprises providing a third device for holding the plurality of first devices in the array on a detection surface.

lating the first device's output with the force comprise detecting a relatively large signal generated by the first device, then determining if the signal generated by the first device varies at a predetermined rate over a predetermined time, and then concluding that the force is still being applied to the first device.

Further illustratively according to this aspect of the invention, determining the first device's output and corre-

Additionally illustratively according to this aspect of the invention, the first device comprises a coaxial cable including a center conductor, a shield, and between the center conductor and shield, a piezoelectric material.

Illustratively according to this aspect of the invention, the first device comprises a piezoelectric ceramic transducer.

Further illustratively according to this aspect of the value of 0.15 μF. An internal distributed resistance of the piezoelectric transducer **24** is modeled by a resistance **38**. Resistance **38** illustratively has a value of 10 Ω. The output DC termination resistance of the terminals of the piezoelectric transducer **24** is modeled by a resistance **40**. Resistance **40** illustratively has a value of 2.7K Ω. The output termination capacitance of the terminals of the piezoelectric transducer **24** is modeled by a capacitance **42** which also illustratively has a value of 0.15 μF.

The effects of external forces upon piezoelectric transducer **24** can be appreciated from an analysis of this model. Changing only the values of the inductances **30** and **32** and keeping all other component values constant will vary the amplitude of the voltage across resistance **40**. Changing the frequency of the applied electrical signal causes a change in the transducer **24**'s characteristic impedance. Changes in the impedance of the system can be correlated with changes in its mechanical analog. FIG. **2** illustrates the transducer **24**'s frequency responses in the frequency range $1 \text{ KHz} \leqq f \leqq 12 \text{ MHz}$. Each trace is the result of a sweep for a different value of inductances **30**, **32** in the model. Results for inductance values from 1 to 10 μH in 1 μH steps are included.

As FIG. **2** illustrates, the frequency response changes with the change in the inductance. Also, as expected, the frequency of peak magnitude changes with changes in the inductance. In practice, these characteristics can be used for detection of a static applied force on a piezoelectric transducer **24** resulting in a sensor device much like a load beam. By connecting a controllable voltage source to piezoelectric transducer **24**, and sweeping the signal frequency, the piezoelectric transducer **24**'s reactance to the signal can be determined, and from the reactance the amount of pressure that is being applied to the piezoelectric transducer **24**. Testing pressure can be applied in the form of gas pressure, water pressure, other fluid pressure, or the mass of an object such as, for example, a patient lying still in a hospital bed. Sensors can be constructed using, for example, sheet piezoelectric transducers **24**, coaxial cable piezoelectric transducers **24**, or ceramic piezoelectric transducers **24**.

Devices incorporating piezoelectric transducers **24** can be used as bed exit or patient monitoring systems on, for example, hospital beds. Two different modes of operation can be realized. In a first, dynamic mode of operation, motion of the object, for example, a patient in a hospital bed, modulates the force on the piezoelectric transducer **24**, causing the piezoelectric transducer to generate an electric signal. Filtering and signal detection algorithms permit the presence of the object and, where a plurality of piezoelectric transducers **24** are used, the location of the object, to be determined accurately. A limitation of this mode of operation is that when the object is not modulating the applied force, that is, not moving, the signal from the piezoelectric transducer **24** practically disappears. Under these circumstances, operation in a second, static mode is indicated. In the situation where the object is still on the sensor but not moving, the detection system switches to the static mode of operation. A signal is applied to the piezoelectric transducer and the characteristic impedance is measured. As described before, this characteristic impedance is used to determine the pressure being (or not being) applied to the sensor by the object (or lack of object). A determination is then made if the object is still on the bed surface or not.

Other algorithms can be applied to increase the reliability of the subject location method and apparatus. As the object moves toward the edge of the bed, a relatively large signal is generated by the piezoelectric transducer **24**. This relatively large signal puts the detection system on notice or arms it. If the signal then varies, for example, diminishes, at a predetermined rate over a predetermined time, the detection system algorithm concludes that the object is still on the surface of the bed and there is no exit. If however, the signal created by the object's movement toward the edge of the bed abruptly changes to zero or below some minimum threshold, the system algorithm immediately switches to the above-described static mode to determine if a constant pressure is being applied or if, instead, the bed is empty. This reduces the number of false alarms which would otherwise result from the object rolling over in bed and then lying still.

Sensitivities to mechanical motion are dependent upon mechanical sensitivities of the piezoelectric transducers **24**, for example, sheets, cables or ceramic transducers, and the material used. Ceramic transducers **24** are manufactured by many suppliers who custom fabricate different sizes, shapes, electrical and physical characteristics. An array of such ceramic piezoelectric transducers **24** arranged across the detection surface can be constructed using a pad or other mechanism for holding the piezoelectric transducers **24** in place. The piezoelectric transducers **24** can also be placed at strategic load bearing points, similar to a traditional load cell application in a weight measurement device. Piezoelectric film transducers **24** are flexible and relatively inexpensive. Again, many suppliers custom fabricate shapes, thicknesses and impregnation of different types of materials. A sheet of such material or an array of isolated sensors made from a polymer impregnated sensor can be fabricated into a suitable detection system. A polymer coaxial cable manufactured by AMP. (Part nos. 0-1001697-0 and 0-1002399-0) is a traditional coaxial cable, but the electrical insulator between the center conductor and the shield is a piezoelectric polymer. The shield provides a high level of electrostatic isolation, and its configuration makes installing standard BNC connectors relatively straightforward. However, its use in static mode applications is inhibited due to the already physical containment of the piezoelectric material. Its construction incorporating the shield and center conductor tends to reduce the effects of external forces applied to the piezoelectric polymer insulator, making static mode detection a less than optimal strategy. However, as a component of a dynamic mode detector, this material is very effective.

FIG. **3** illustrates a system incorporating various ones of the above described features into a bed exit or patient monitoring system **50** for, for example, a hospital bed **52**. The system **50** includes an array **54** of piezoelectric transducers **56** which may, for example, be separate areas of a piezoelectric film of the type described above, electrically isolated from each other and from their surroundings, or ceramic piezoelectric transducers of the type described above, mounted in, for example, a textile or resin retainer **58** which provides electrical isolation of the various transducers **56** from each other and from their surroundings. The separate transducers **56** are each coupled to one terminal of respective single pole, double throw switches . . . **60**-*c*, . . . **60**-*d*, . . . **60**-*e*, . . . **60**-*f*, . . . and so on. Switches **60** may be hardware switches or electronic solid state switches, but may also be executed in software or firmware in, for example, a personal computer (PC) **62** which controls switches **60** according to an algorithm of the type described above which PC **62** is programmed to execute. One throw of each switch **60** is coupled to, for example, an analog-to-digital (A/D) input/output (I/O) port of PC **62** to receive the output signals from the respective transducers **56** when the system **50** is operating in the dynamic mode described above. These output signals from the transducers **56** may, for example, be time-division multiplexed into the PC **62**. The other throw of each switch **60** is coupled to a signal generator **64**. While separate signal generators . . . **64**-*c*, . . . **64**-*d*, . . . **64**-*e*, . . . **64**-*f*, . . . and so on, are illustrated for each respective switch . . . **60**-*c*, . . . **60**-*d*, . . . **60**-*e*, . . . **60**-*f*, . . . and so on, fewer signal generators can be employed. For example, it is contemplated that a signal generator **64** may be implemented as an output device of PC **62**, or PC **62** may incorporate a digital waveform synthesis routine, with the synthesized waveform being appropriately processed, for example, amplified by an output device of PC **62**, or directly supplied to the switches . . . **60**-*c*, . . . **6**-*d*, . . . **60**-*e*, . . . **60**-*f*, . . . and so on. The signal generator(s) **64** will ordinarily be under the control of the PC **62**, and will only be activated when it (they) is (are) required, such as, for example, when the system **50** is operating in the static mode described above. If the signal generator(s) **64** is (are) implemented by synthesizing it (them), the signal generator **64** output(s) can also be time-division multiplexed among the transducers **56** that require excitation in the static mode of operation. And, as noted, whatever transducer(s) **56** is (are) excited by the signal generator **64** will need to be monitored, illustratively by the PC **62**'s A/D I/O port, to determine, for example, the voltage(s) across the transducer(s) **56** in response to excitation. From this (these) measure(s), the impedance(s) of the transducer(s) **56** being excited can be determined, and from the impedance(s), the force(s) on the transducer(s) **56** being excited.

What is claimed is:

1. A monitoring system comprising a first, piezoelectric device which is subject to a force to be monitored, and a second device for determining the first device's output and for correlating the first device's output with the force, the second device including a sweep signal generator for causing a sweeping signal to be applied to the first device and an impedance determining circuit for causing the impedance of the first device to the applied swept signal to be determined.

2. The apparatus of claim **1** comprising a plurality of said first devices coupled together in an array.

3. The apparatus of claim **1** wherein the second device comprises a switch for controlling the second device for determining the first device's output and for correlating the first device's output with the force, the switch having a first state corresponding to a first mode of operation of the second device and a second state corresponding to a second mode of operation of the second device.

4. The apparatus of claim **3** wherein switching of the switch to the second state causes a signal to be applied by the signal generator to the first device and causes the second device to determine the impedance of the first device to the applied signal.

5. The apparatus of claim **4** wherein the second device comprises a second device for determining from the impedance the force applied to the first device.

6. The apparatus of claim **5** wherein the second device comprises a second device for determining from the determined force whether an object is on the first device.

7. The apparatus of claim **3** wherein the second device comprises a second device for detecting a relatively large signal generated by the first device, placing the second

device in a second state when the signal decreases over a brief time interval below some minimum threshold, then switching to the second mode, and determining if a relatively constant force is being applied.

9. The apparatus of claim **4** wherein the second device comprises a second device for determining from the first device's impedance the force that is being applied to the first device.

10. The apparatus of claim **1** wherein the first device comprises a piezoelectric ceramic transducer.

11. The apparatus of claim **10** comprising an array of said piezoelectric ceramic transducers.

12. The apparatus of claim **10** wherein the ceramic transducer is custom fabricated to a particular size, shape, and electrical properties.

13. The apparatus of claim **2** further comprising a third device for holding the plurality of first devices in the array.

14. The apparatus of claim **10** wherein the first device is oriented at a strategic load-bearing point.

15. The apparatus of claim **10** comprising a plurality of first devices coupled together and oriented at a plurality of strategic load bearing points.

16. The apparatus of claim **10** wherein the second device comprises a switch for controlling the second device for determining the first device's output and for correlating the first device's output with the applied force, the switch having a first state corresponding to a first mode of operation and a second state corresponding to a second mode of operation.

17. The apparatus of claim **16** wherein switching of the switch to the second state causes a signal to be applied by the signal generator to the first device and causes the second device to determine the impedance of the first device to the applied signal.

18. The apparatus of claim **17** wherein the second device comprises a second device for determining from the impedance the force on the first device.

19. The apparatus of claim **18** wherein the second device comprises a second device for determining from the determined force whether an object is exerting force on the first device.

20. The apparatus of claim **16** wherein the second device comprises a second device for detecting a relatively large signal generated by the first device, placing the second device in a second state when the relatively large signal from the first device is detected, then determining if the signal generated by the first device varies at a predetermined rate over a predetermined time, and then concluding that an object is exerting force on the first device.

21. The apparatus of claim **16** wherein the second device comprises a second device for detecting a relatively large signal generated by the first device, placing the second device in a second state when the signal decreases relatively rapidly to below a minimum threshold, then switching to the second mode, and then determining if a relatively constant force is being applied on the first device.

22. The apparatus of claim **17** wherein the second device comprises a second device for determining from the first device's impedance the force applied to the first device.

23. The apparatus of claim **1** wherein the first device

[redacted]

first devices's output with the force, the switch having a first

[redacted]

[redacted]

comprises a second device for detecting a relatively large

[redacted]

54. The method of claim **52** wherein providing a piezoelectric ceramic transducer comprises custom fabricating a piezoelectric ceramic transducer to a particular size, shape, and electrical properties.

55. The method of claim **53** wherein providing an array of said first devices coupled together further comprises providing a third device for holding the plurality of first devices in the array.

56. The method of claim **52** further comprising orienting the first device at a strategic load-bearing point.

57. A monitoring method comprising providing a first, piezoelectric device which is subject to a force to be monitored, determining the first device's output, and correlating the first device's output with the force; wherein determining the first device's output comprises providing a switch having a first state when the force applied to the first device is being modulated and a second state when the force applied to the first device is not being modulated, providing a signal generator for causing a signal to be applied to the first device, and providing an impedance determining circuit

lating the first device's output with the force; determining the first device's output including providing a signal generator for causing a signal to be applied to the first device and providing an impedance determining circuit for causing the impedance of the first device to the applied signal to be determined; and wherein providing a first device includes providing a coaxial cable including a center conductor, a shield, and a piezoelectric material between the center conductor and shield.

69. The method of claim **68** wherein determining the first device's output comprises providing a switch having a first state when the force applied to the first device is being modulated and a second state when the force applied to the first device is not being modulated.

70. The method of claim **69** wherein determining the first device's output and correlating the first device's output with the object's status comprise determining from the impedance the force on the firs device.

71. The method of claim **70** wherein determining the first device's output and correlating the first device's output with