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Riley**

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(54) MONITORING SYSTEM AND METHOD

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(52) U.S. Cl. 340/665; 340/666; 340/667; 73/862.045
(58) Field of Search 340/665-667, 340/657, 658, 573.1, 666; 73/760, 862.045, 862.046; 345/173

(57) ABSTRACT

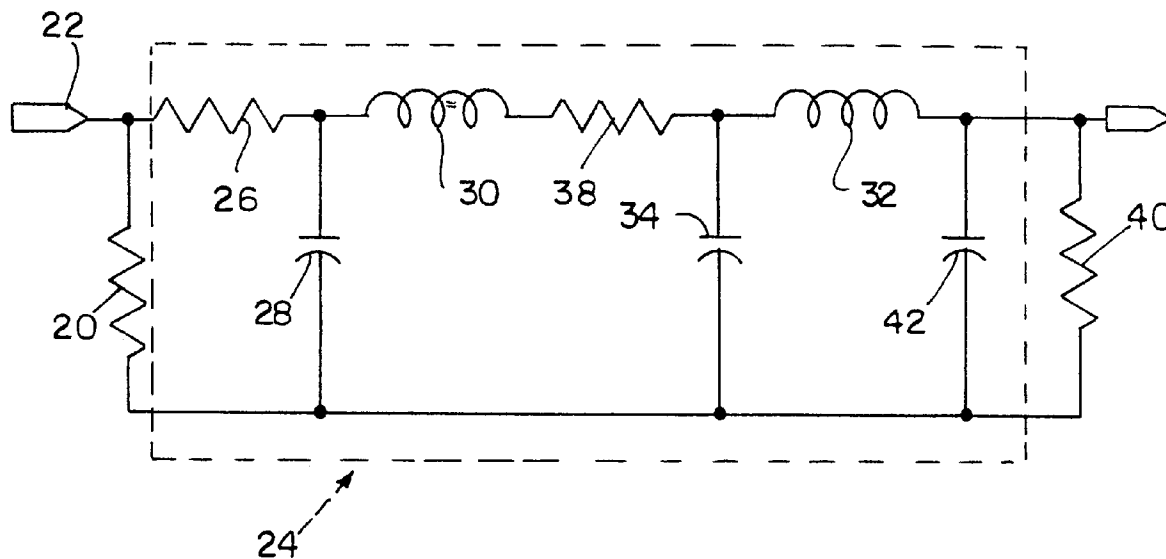
A system including piezoelectric material wherein a force exerted on the piezoelectric material is determined by subjecting the piezoelectric material to an input signal of sweeping frequency and evaluating the response of the piezoelectric material to the applied signal.

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67 Claims, 3 Drawing Sheets



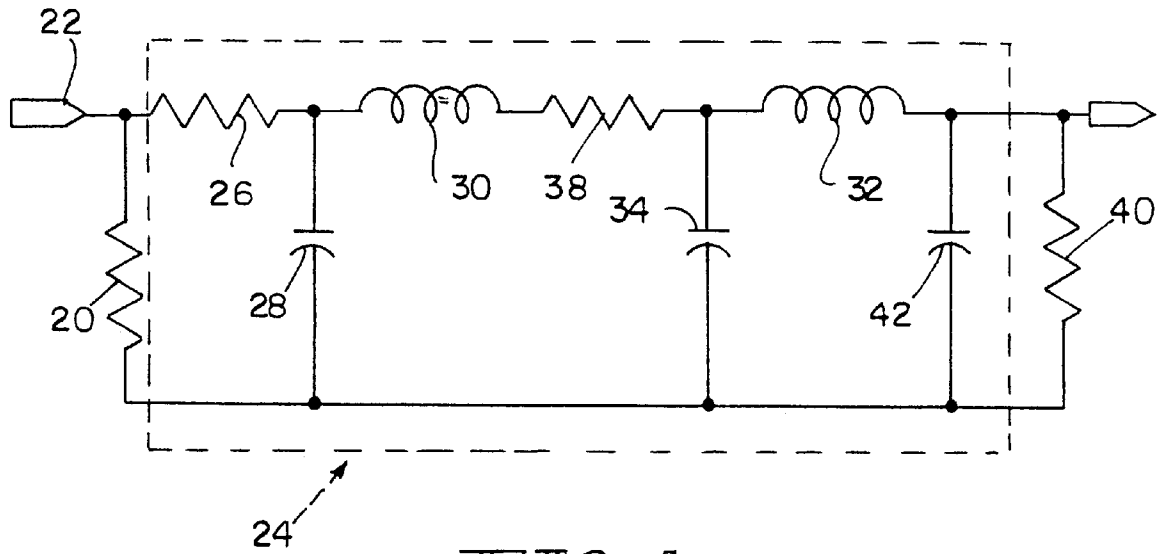
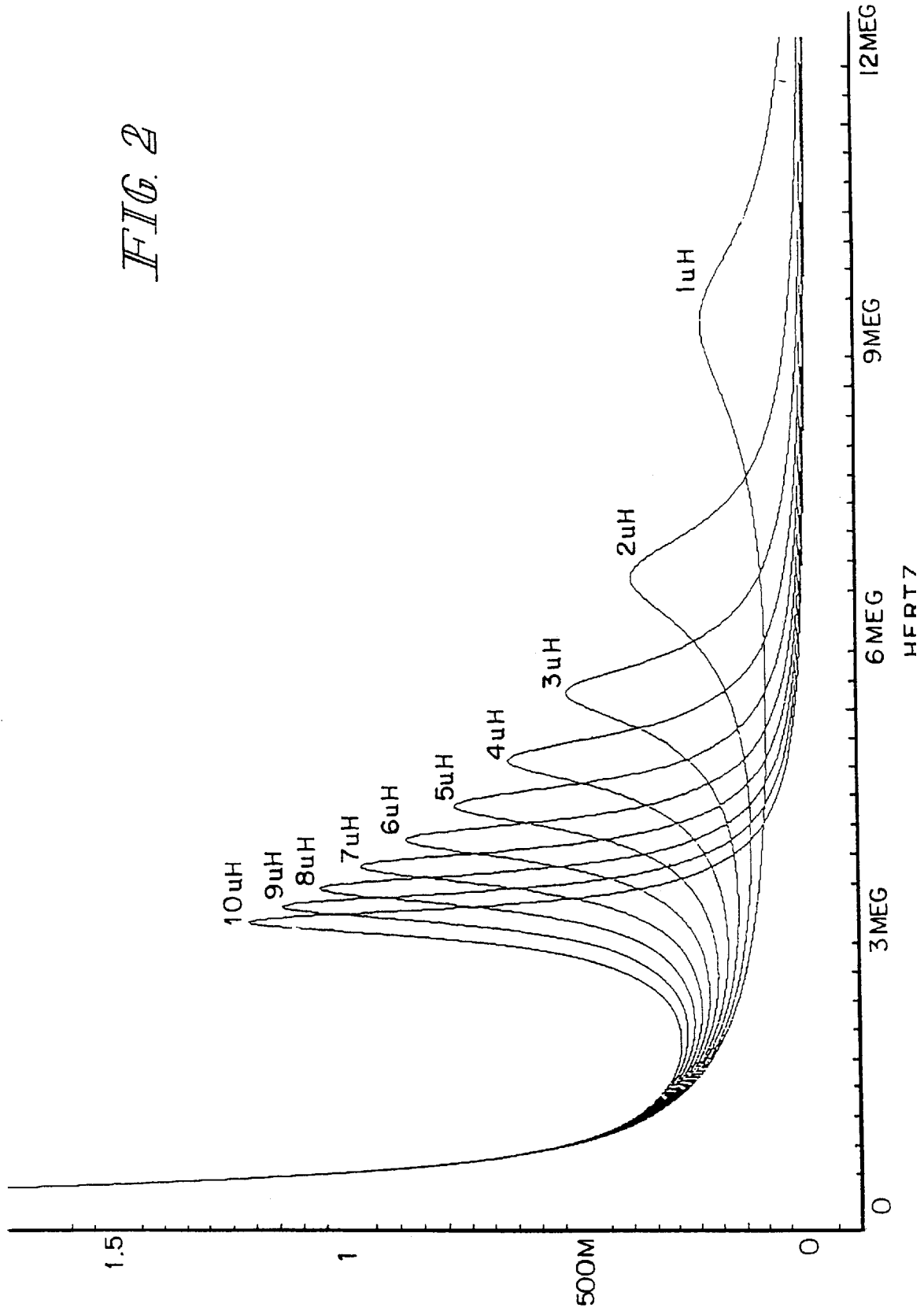


FIG. 1

FIG. 2



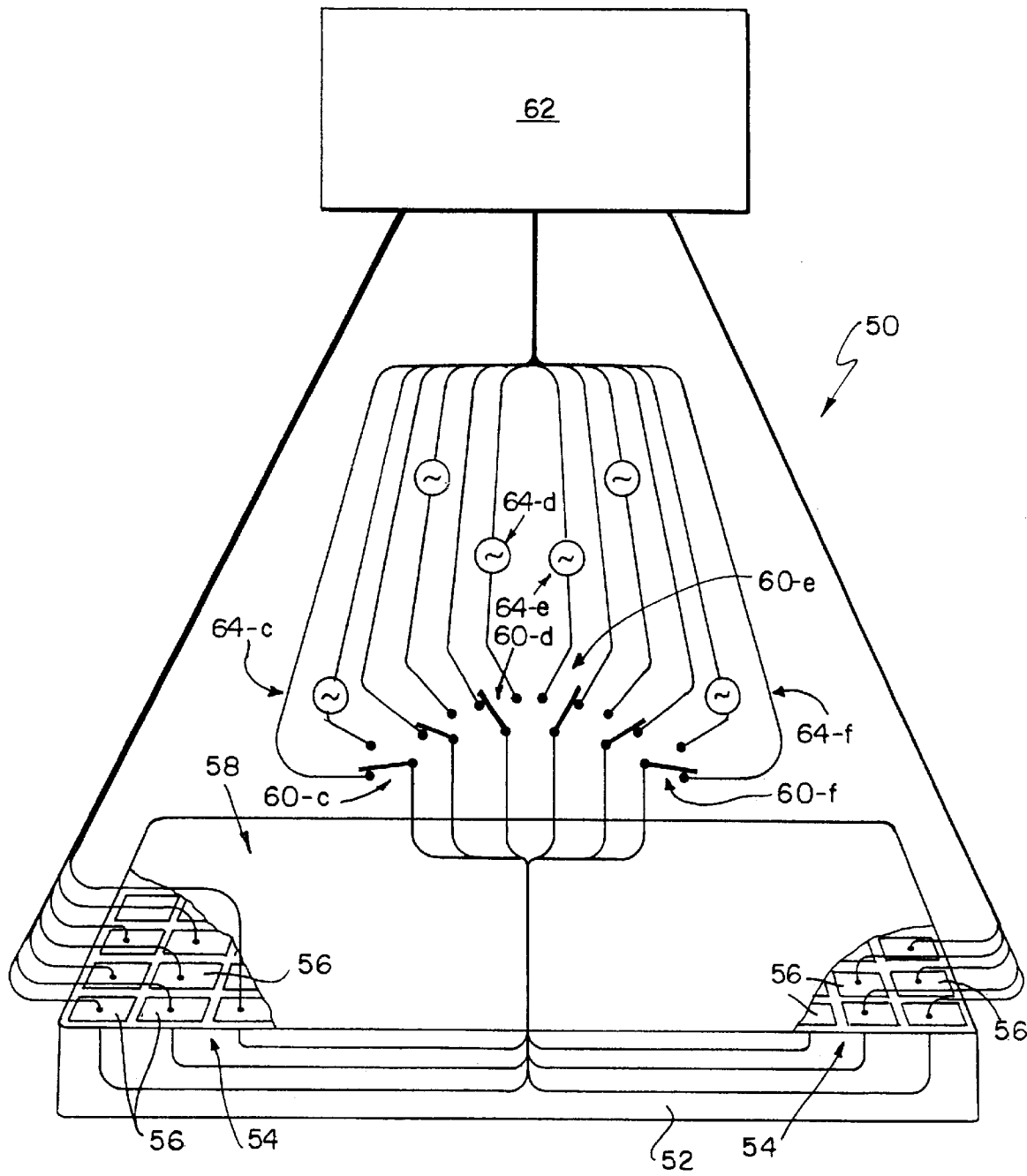


FIG. 3

MONITORING SYSTEM AND METHOD
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.

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

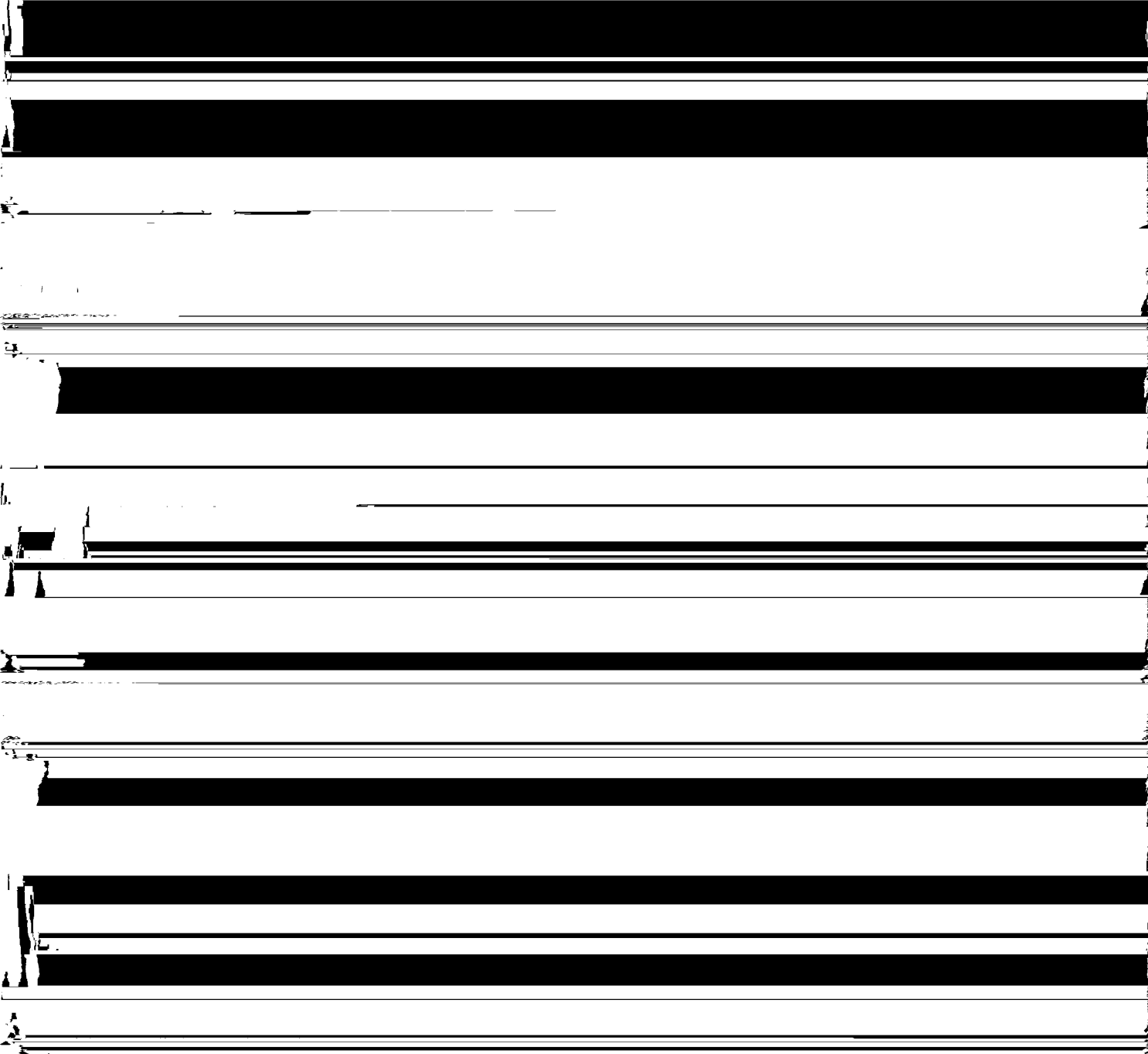
Illustratively according to this aspect of the invention, switching of the switch to the second state causes a signal to be applied to the first device and causes the impedance of the first device to the applied signal to be determined.

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

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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 correlating the first device's output with the force comprise detecting a relatively large signal generated by the first device, then detecting when the signal abruptly decreases below some minimum threshold, and then determining if a constant force is being applied.

According to another aspect of the invention, a monitoring system comprises 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

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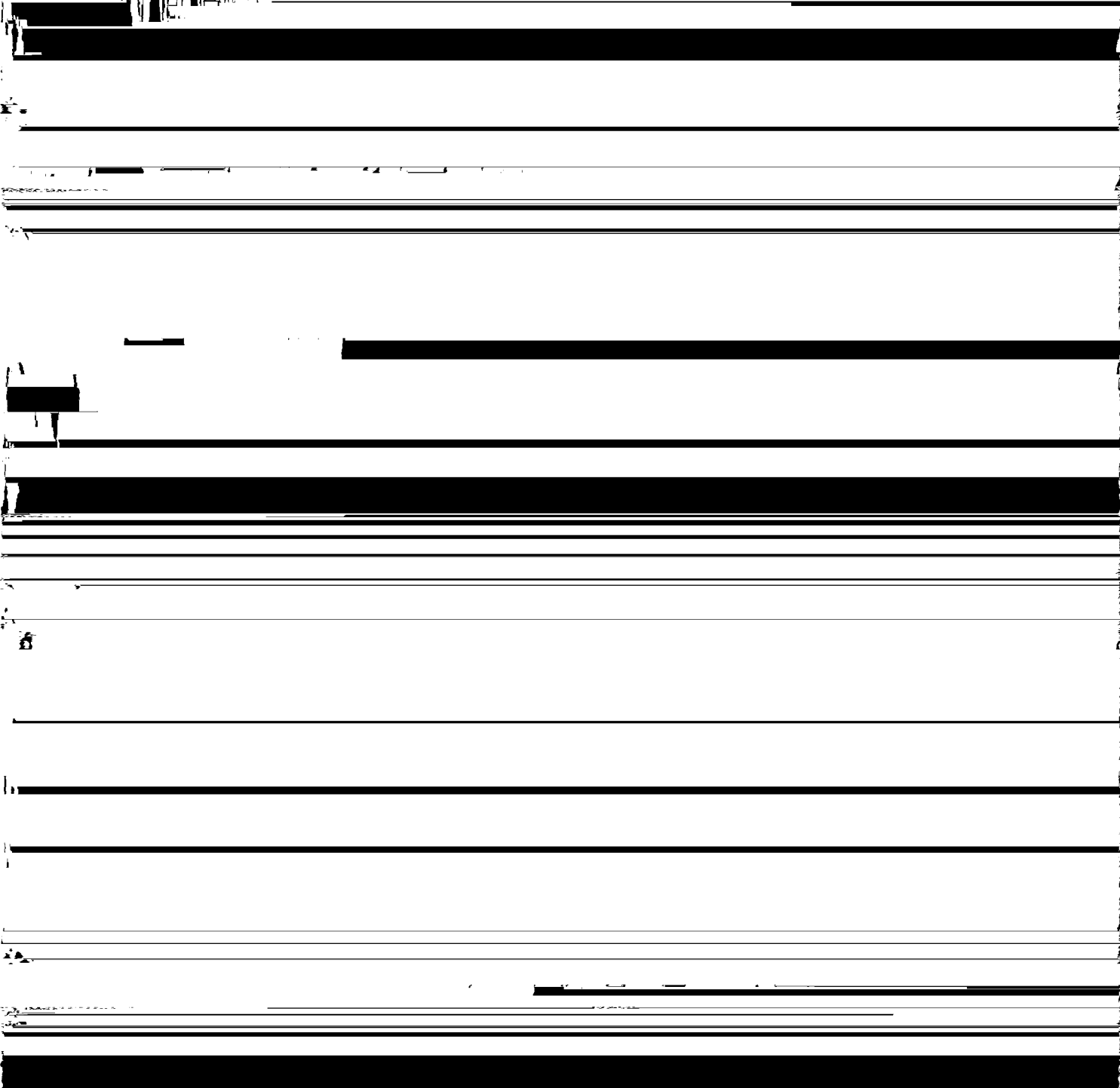
ing a center conductor, a shield, and between the center conductor and shield, a piezoelectric material.

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

5 Further illustratively according to this aspect of the invention, the first devices are formed into an array, the apparatus further comprising a third device for holding the plurality of first devices in the array on a detection surface.

10 Additionally illustratively according to this aspect of the invention, the piezoelectric transducer is custom fabricated to a particular size, shape, and electrical properties.

Illustratively according to this aspect of the invention, the first device is oriented at a strategic load-bearing point.



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 2.7 K 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 $1 \text{ KHz} \leq f \leq 12 \text{ MHz}$. 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

tion 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 fabric matrix 58.

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, . . . 60-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 piezoelectric device which is subject to dynamic and static forces whose magnitude is to be monitored and which generates a signal for a change of force; and
- a second device including a switch having a first state and a second state for switching the second device between

the first mode corresponding to the first state and second

generated by the piezoelectric device, placing the second device in the second mode when the relatively large signal is detected, then determining if the signal generated by the piezoelectric device varies at a predetermined rate over a predetermined time, and then concluding that an object is still exerting force on the piezoelectric device.

9. The apparatus of claim 1 wherein the second device comprises a device for detecting a relatively large signal generated by the piezoelectric device, then placing the second device in the second mode when the signal decreases over a brief time interval below some minimum threshold, and then determining if a relatively constant force is being applied.

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

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

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 10 wherein the piezoelectric device is oriented at a strategic load-bearing point.

14. The apparatus of claim 10 comprising a plurality of piezoelectric devices coupled together and oriented at a plurality of strategic load bearing points.

15. The apparatus of claim 1 wherein the second device comprises a device for determining from the determined force whether an object is exerting force on the piezoelectric device.

16. The apparatus of claim 1 wherein the second device comprises a device for detecting a relatively large signal generated by the piezoelectric device, placing the second device in the second mode when the relatively large signal from the piezoelectric device is detected, then determining

25. The apparatus of claim 1 wherein the second device comprises a device for detecting a relatively large signal generated by the piezoelectric device, placing the second device in the second mode when the relatively large signal from the piezoelectric device is detected, then determining if the signal generated by the piezoelectric device varies at a predetermined rate over a predetermined time, and then concluding that an object is exerting force on the piezoelectric device.

26. The apparatus of claim 23 wherein the second device comprises a device for sweeping the signal frequency and determining the piezoelectric device's impedance in response to the swept signal frequency.

27. A monitoring method comprising:

providing a piezoelectric device which is subject to dynamic and static forces whose magnitude is to be monitored and which generates a signal for a change of force;

detecting signals generated by the piezoelectric device for dynamic forces;

determining the magnitude of force from the detected signal for dynamic forces;

determining the impedance of the piezoelectric device for static forces if the generated signals are not detected; and

determining the magnitude of force from the impedance for static forces.

28. The method of claim 27 wherein determining the impedance of the piezoelectric device comprises providing electrical signals for exciting the piezoelectric device and determining the piezoelectric transducer's response to the electrical signals.

29. The method of claim 27 wherein providing a piezoelectric device comprises providing a plurality of said piezoelectric devices coupled together in an array.

30. The method of claim 27 wherein detecting signals generated by the piezoelectric device comprises providing a switch having a first state corresponding to a first mode of operation when the force applied to the piezoelectric device is being modulated and a second state corresponding to a second mode of operation when the force applied to the piezoelectric device is not being modulated.

31. The method of claim 30, including detecting a relatively large signal generated by the piezoelectric device, then determining if the signal generated by the piezoelectric device varies at a predetermined rate over a predetermined time, and then concluding that an object is still on the piezoelectric device.

32. The method of claim 30, including detecting a relatively large signal generated by the piezoelectric device, then detecting when the signal decreases relatively rapidly to below a minimum threshold, and then determining if a relatively constant force is being applied.

33. The method of claim 30 wherein switching of the switch to the second state causes a signal to be applied to the piezoelectric device and causes the impedance of the piezoelectric device to the applied signal to be determined.

34. The method of claim 33 further comprising determining from the force whether an object is on the piezoelectric device.

35. The method of claim 33 wherein determining the impedance of the piezoelectric device comprise sweeping the applied signal's frequency and determining the piezoelectric device's impedance in response to the swept signal frequency.

36. The method of claim 27 wherein providing a piezoelectric device comprises providing a piezoelectric ceramic transducer.

37. The method of claim 36 wherein providing a piezoelectric ceramic transducer comprises providing an array of piezoelectric ceramic transducers.

38. The method of claim 37 wherein providing an array of said piezoelectric devices coupled together further comprises providing a third device for holding the plurality of piezoelectric devices in the array.

39. The method of claim 36 wherein providing a piezoelectric ceramic transducer comprises custom fabricating a piezoelectric ceramic transducer to a particular size, shape, and electrical properties.

40. The method of claim 36 further comprising orienting the piezoelectric device at a strategic load-bearing point.

41. The method of claim 36 including providing a switch having a first state when the force applied to the piezoelectric device is being modulated and a second state when the force applied to the piezoelectric device is not being modulated.

42. The method of claim 41 wherein determining the impedance of the piezoelectric device's comprise providing electrical signals for exciting the piezoelectric device and determining the impedance of the piezoelectric device to the electrical signals.

43. The method of claim 42, including determining from the determined force whether an object is exerting force on the piezoelectric device.

44. The method of claim 42 including detecting a relatively large signal generated by the piezoelectric device, then determining if the signal generated by the piezoelectric device varies at a predetermined rate over a predetermined time, and then concluding that the object is exerting force on the piezoelectric device.

45. The method of claim 42 wherein providing electrical signals for exciting the piezoelectric device and determining the impedance of the piezoelectric transducer to the electrical signals comprise sweeping the applied signal's frequency and determining the piezoelectric transducer's impedance in response to the swept signal frequency.

46. The method of claim 41 including detecting a relatively large signal generated by the piezoelectric device, then detecting when the signal decreases relatively rapidly to below a minimum threshold, and then determining if a constant force is being applied.

47. The method of claim 36 wherein providing a piezoelectric device comprises providing a plurality of piezoelectric devices coupled together and oriented at a plurality of strategic load-bearing points.

48. The method of claim 27 wherein providing a piezoelectric device comprises providing a flexible piezoelectric film.

49. The method of claim 48 wherein providing a flexible piezoelectric film comprises custom fabricating a flexible piezoelectric film to a particular size, shape, and electrical properties.

50. The method of claim 48 wherein providing a flexible piezoelectric film comprises providing an array of said piezoelectric device.

51. The method of claim 48 including providing a switch having a first state when the force applied to the piezoelectric device is being modulated and a second state when the force applied to the piezoelectric device is not being modulated.

52. The method of claim 51 including detecting a relatively large signal generated by the piezoelectric device, then determining if the signal generated by the piezoelectric device varies at a predetermined rate over a predetermined time, and then concluding that the object is exerting force on the piezoelectric device.

53. The method of claim 51 including providing electrical signals for exciting the piezoelectric device and determining the impedance of the piezoelectric device to the electrical signals.

54. The method of claim 53 including determining from the determined force whether the object is exerting force on the piezoelectric device.

55. The method of claim 53 wherein providing electrical signals for exciting the piezoelectric device and determining the impedance of the piezoelectric device to the electrical signals comprise sweeping the applied signal's frequency and determining the piezoelectric device's impedance in response to the swept signal frequency.

56. The method of claim 51 including detecting a relatively large signal generated by the piezoelectric device, then detecting when the signal decreases relatively rapidly to below a minimum threshold, and then determining if a constant force is being applied.

57. The method of claim 27 wherein providing a piezoelectric transducer comprises providing a coaxial cable including a center conductor, a shield, and a piezoelectric material between the center conductor and shield.

58. The method of claim 57 including providing a switch having a first state when the force applied to the piezoelectric device is being modulated and a second state when the force applied to the piezoelectric device is not being modulated.

59. The method of claim 58 wherein determining the impedance of the piezoelectric device comprise providing electrical signals for exciting the piezoelectric device and determining the impedance of the piezoelectric transducer to the electrical signals.

60. The method of claim 59, including determining from the determined force whether the object is exerting force on the.

61. The method of claim 59 wherein providing electrical signals for exciting the piezoelectric device and determining the impedance of the piezoelectric device to the electrical signals comprise sweeping the applied signal's frequency and determining the piezoelectric device's impedance in response to the swept signal frequency.

62. The method of claim 58 including detecting a relatively large signal generated by the piezoelectric device, then determining if the signal generated by the piezoelectric device varies at a predetermined rate over a predetermined time, and then concluding that the object is exerting force on the piezoelectric device.

63. The method of claim 58 including detecting a relatively large signal generated by the piezoelectric device, then detecting when the signal decreases relatively rapidly to below a minimum threshold, and then determining if a constant force is being applied.

64. A monitoring system comprising:

a piezoelectric device which is subject to a force whose magnitude is to be monitored and which generates a signal for a change of force; and

a second device for detecting a relatively large signal generated by the piezoelectric device, determining if the signal generated by the piezoelectric device after the detected relatively large signal varies at a predetermined rate over a predetermined time, and if so, concluding that an object is still exerting force on the piezoelectric device.

65. A monitoring system comprising:

a piezoelectric device which is subject to a force whose magnitude is to be monitored and which generates a signal for a change of force; and

a second device switching between a first mode and second mode for detecting a relatively large signal generated by the piezoelectric device and determining if the signal generated by the piezoelectric device after the detected relatively large signal decreases over a brief time interval below some minimum threshold in a first mode, and if so, determining if a relatively constant force is being applied in a second mode.

66. A monitoring method comprising:

providing a piezoelectric device which is subject to a force whose magnitude is to be monitored and which generates a signal for a change of force;

detecting a relatively large signal generated by the piezoelectric device;

determining if the signal generated by the piezoelectric device after the detected relatively large signal varies at a predetermined rate over a predetermined time; and

if so, concluding that an object is still exerting force on the piezoelectric device.

67. A monitoring method comprising:

providing a piezoelectric device which is subject to a force whose magnitude is to be monitored and which generates a signal for a change of force;

detecting a relatively large signal generated by the piezoelectric device;

determining if the signal generated by the piezoelectric device after the detected relatively large signal decreases over a brief time interval below some minimum threshold; and

if so, determining if a relatively constant force is being applied.

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