

FORCE MEASURING DEVICES

The present invention is directed to devices for measuring forces applied at any given particular time and
5 for producing continuous, or analog, outputs in response to those forces.

While such devices for production of analog outputs are not unknown in the prior art, most such devices have, at least in part, incorporated therein some mechanical
10 linkage between a force sensing element and an output producing element. These mechanical linkages vary in complexity, but generally involve a plurality of levers, cams, or the like to transmit the mechanical deflection imposed upon the device by the force to be detected to
15 the output producing element of the device. Output producing elements may, for example, be potentiometers, variable inductance coils, variable capacitors having movable plates, and the like. It is a general maxim that the more moving parts contained in a device, the more
20 there is that can go wrong with that device. Conversely, the fewer the parts contained in a device, the less prone the device is to breakdown and, hence, the more reliable the device. Thus, the most reliable device is often the device having the fewest moving parts therein.

25 The economics of a device are also of significant importance and such characteristics as a lower cost of construction, simplicity of construction, durability and a wide range of applications for a given technology are all important considerations in determining the economic
30 success of a device.

In accordance with the present invention, a force measuring device comprises a first electrically
35 relationship with said second means and responsive to a

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force moving said first means with respect to said second means to vary an electrical property of said device proportionally to said force; said second means being a substantially rigid non-conductive substrate with
5 electrically propertied lands affixed thereto, and said first means being a substantially flexible non-conductive substrate with electrically propertied lands affixed thereto;

10 said device further comprising spacer means disposed intermediate said first means and said second means to maintain, in an at rest position, said first means and said second means in spaced, substantially parallel relationship; said spacer means having a plurality of apertures therethrough; said apertures allowing
15 electrical communication therethrough between said electrically propertied lands of said first means and said electrically propertied lands of said second means; and

20 said device further comprising means for applying said force to said first means, said means for applying said force comprising a plurality of actuators carried upon a common actuator assembly, said plurality of actuators being capable of selectively impinging upon various areas of said first means in register with said
25 apertures.

Preferably: said plurality of actuators equals said plurality of apertures; and each of said plurality of actuators is in register with one of said plurality of apertures; and said actuators are capable of impinging
30 upon more than one area of said first means simultaneously.

The common actuator assembly may be of the joystick-type comprising a common actuator carrier moved by a single control stick. A further enhancement is the
35 addition directly below the control stick of a Z-actuator operated by its own Z-control means. Thus, analog

control can be achieved employing the present invention in the X-axis, the Y-axis and the Z-axis.

In such a particularly preferred arrangement, the force measuring device may comprise a first
5 non-conductive substrate, a second non-conductive substrate, an actuator means and a spacer means;

said first substrate being substantially flexibly resilient and having a first plurality of electrically resistive lands affixed thereto; said second substrate
10 being substantially rigid and having a second plurality of electrically resistive lands affixed thereto; said spacer means being intermediate said first substrate and said second substrate and, in an at rest position, maintaining said substrates in spaced, substantially
15 parallel relation; each of said first plurality of resistive lands being in facing relation with and in register with one of said second plurality of resistive lands, said spacer means having a plurality of apertures therethrough, each of said plurality of apertures being
20 in register with one of said first plurality of resistive lands;

said actuator means comprising a plurality of elastomeric actuators, a common actuator carrier and a common control means; each of said plurality of
25 actuators being in register with one of said first plurality of resistive lands, each of said actuators being connected to said common actuator carrier, and said common actuator carrier being connected to and responsive to said common control means.

30 Preferably: said actuator means further comprises a Z-control means and a Z-actuator; said plurality of apertures, said first plurality of resistive lands, and said second plurality of resistive lands each being equal in number to and respectively in register with said
35 plurality of actuators plus said Z-actuator; said

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In a particularly preferred arrangement, the force measuring device may comprise a first non-conductive
5 substrate, a second non-conductive substrate, an actuator means and a spacer means;

said first substrate being substantially flexibly resilient and having a first plurality of electrically resistive lands affixed thereto; said second substrate
10 being substantially rigid and having a second plurality of electrically resistive lands affixed thereto; said spacer means being intermediate said first substrate and said second substrate and, in an at rest position, maintaining said substrates in spaced, substantially
15 parallel relation; each of said first plurality of resistive lands being in facing relation with and in register with one of said second plurality of resistive lands, said spacer means having a plurality of apertures therethrough, each of said plurality of apertures being
20 in register with one of said first plurality of resistive lands; said first substrate being responsive to a force moving said first substrate with respect to said second substrate, through one or more of said apertures, to vary the conductivity of said device proportionally to said
25 force;

said actuator means being capable of applying said force to said first substrate and comprising a plurality of elastomeric actuators, a common actuator carrier and a common control means; each of said plurality of
30 actuators being in register with one of said first plurality of resistive lands, each of said actuators being connected to said common actuator carrier, and said common actuator carrier being connected to and responsive to said common control means.

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Preferably: said actuator means further comprises a Z-control means and a Z-actuator; there being an additional aperture through said spacer means, and additional electrically resistive lands affixed to said first and second substrates, associated with and in register with said Z-actuator; said

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Z-control means being connected to said Z-actuator and operable independently from said common control means.

In operation of the particularly preferred arrangement, application of a given amount of force will
5 establish an initial minimal contact area between a resistive land or area of the flexible substrate and a resistive land or area of the rigid substrate. An increase in the force applied to the flexible substrate will increase the contact area between the two resistive
10 areas. This increase in contact area serves to reduce the resistivity of the electrical connection between the two resistive areas, which in turn increases the conductivity of that electrical contact in proportion to the amount of force applied to the flexible substrate.
15 Thus, an increase in the physical force applied to the flexible substrate results in a proportional increase in the conductivity of the device. When an electrical potential is applied across the device, that is across the two resistive areas, an increase in force applied to
20 the flexible substrate is manifested by an increase in current flow through the device via the electrical contact area between the two resistive areas.

The resiliency of the flexible substrate returns the flexible substrate to its original position and thereby
25 may break electrical contact between the two resistive areas when the force is removed from the flexible substrate.

A variation involves inversion of one of the substrates (either the rigid or the flexible substrate)
30 so that movement of the flexible resistive area toward the rigid resistive area would result not in resistive coupling but in capacitive coupling proportional to the amount of force applied, since an increase in the amount of force applied would bring a greater amount of the
35 resistive area on the flexible substrate in parallel

relation with the resistive area on the rigid substrate and, consequently, increase the capacitance between the two resistive areas proportionally as the force applied to the flexible substrate is increased.

5 A further variation is accomplished by replacement of the resistive area on the rigid substrate with a printed spiral-like inductive pattern. With such a configuration, application of a force through the flexible substrate would progressively short out more
10 turns of the spiral-like inductive pattern on the rigid substrate through contact with the resistive area on the flexible substrate, thus reducing the inductance of that pattern as the amount of force applied to the flexible substrate is increased. The inductance of the inductive
15 pattern printed on the rigid substrate is thereby varied proportionally to the amount of force applied to the flexible substrate.

Two force measuring devices, in accordance with the present invention, and various resistive, capacitive and
20 inductive couplings of general interest, will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a side view of a schematic section through a resistive coupling;

25 Figure 2 is an exploded perspective view of part of Figure 1;

Figure 3 is a side view similar to Figure 1 but showing finger operation;

30 Figure 4 is a top view of a schematic drawing representing the change of electrical contact area which occurs in Figure 1 with a change of applied force;

Figure 5 is a side view of a schematic drawing representing two resistive areas in adjacent position, with no force applied, and omitting any spacer means;

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Figure 6 is a side view of a schematic drawing representing the interaction of the resistive areas of Figure 5 with a force applied to the upper area;

5 Figure 7 is a side view of a schematic drawing representing the interaction of the resistive areas of Figure 5 with a force applied to the upper area greater than the force applied in Figure 6;

Figure 8 is a side view of a schematic section through a capacitive coupling;

10 Figure 9 is a top view of a schematic drawing representing an inductive coupling;

Figure 10 is a top view of a schematic drawing representing an inductive pattern similar to that of Figure 9 and showing increased contact area established
15 by the resistive area of the flexible substrate in response to an applied force greater than that shown in Figure 9;

Figure 11 is a side view of a schematic drawing representing an alternative spacer structure with
20 resistive areas within moulded protuberances;

Figure 12 is a side view of a schematic drawing representing a second alternative spacer structure with resistive areas intermediate moulded protuberances;

Figure 13 is a perspective drawing of a first force
25 measuring device in accordance with the present invention; and

Figure 14 is a perspective drawing of a second force
measuring device in accordance with the present invention which is similar to that shown in Figure 13 with an added
30 resistive area and an added actuator for Z-axis operation.

It will be convenient to discuss first the two force measuring devices in accordance with the present invention shown in Figures 13 and 14, and then discuss

the various resistive, capacitive and inductive couplings of general interest shown in Figures 1 to 12.

In Figure 13, a force measuring device 80 has a substantially rigid bottom substrate 82, a spacer 84, and
5 a resiliently flexible upper substrate 86. A plurality of elastomeric actuators 88 is carried on a common actuator carrier 90 which is connected to and operated by a single control stick 92. The spacer 84 has apertures therethrough (not shown) in register with resistive areas
10 94 affixed to the bottom of the upper substrate 86 and similar resistive areas (not shown) affixed to the top of the bottom substrate 82 and in register with the resistive areas 94. The actuators 88 are in register with the resistive areas 94. The device of Figure 13,
15 when connected to appropriate external electronic circuitry (not shown) provides an analog X-Y axis controller adaptable to a variety of applications such as machinery control, electronic games and the like. In operation, the thickness of the spacer 84 may be varied
20 to provide for the actuators 88, when in an at rest position, to effect no electrical contact between the resistive areas on the respective substrates 82 and 86, or a choice of a thinner spacer 84 will allow a minimal contact area between the resistive areas on the
25 respective substrates 82 and 86 to be effected by the actuators 88 when in their at rest position. In such a version of the embodiment of Figure 13, where such minimal contact areas are maintained, the associated external electronic circuitry would necessarily allow for
30 threshold values which must be exceeded before the presence of a force exerted on a respective actuator would be acknowledged.

Figure 14 illustrates another embodiment of the present invention which is similar to the embodiment
35 illustrated in Figure 13, but which has a greater

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plurality of actuators as well as a provision for a Z-axis control. In Figure 14, a force measuring device 100 is shown having a rigid bottom substrate 102, a spacer 104, and a resiliently flexible upper substrate 106; a plurality of actuators 108 is carried on a common actuator carrier 110 which is connected to and controlled by a single control stick 112. Additionally there is a Z-axis actuator 114 which is attached to a control plunger 116. The control plunger 116 is concentrically captured within and freely moves within the control stick 112. Resistive areas 118, apertures (not shown) in spacer 104 and resistive areas (not shown) on substrate 102 are positioned in register with the plurality of actuators 108 and the Z-axis actuator 114 in a manner substantially similar to the manner described in Figure 13. The device of Figure 14, therefore, with its greater number of actuators 108 provides a finer resolution of X-Y control than does the device of Figure 13 with a smaller plurality of actuators 88 and, additionally, the device of Figure 14 with its control plunger 116 acting upon Z-axis actuator 114 and the associated resistive area and aperture in register therewith, provides Z-axis control with a single hand control comprised of control stick 112 and control plunger 116.

The manner in which the above-noted actuators 88 and 108 operate to cause electrical communication between the flexible and rigid substrates will now be discussed initially with reference to a resistive coupling 10 shown schematically in section in Figure 1. The resistive coupling 10 includes a non-conductive rigid substrate 12, a spacer 14 of non-conductive material, and a non-conductive resiliently flexible substrate 16. Affixed to the rigid substrate 12 is a resistive area 18 which is, in the preferred embodiment, comprised of an electrically propertied ink which is silk-screened on the

rigid substrate 12. A similar resistive area 20 is affixed in a similar manner to the flexible substrate 16. The resistive area 18 and the resistive area 20 are in register with each other and with an aperture 22 in the spacer 14 so that electrical contact can be effected between the resistive area 18 and the resistive area 20 through the aperture 22 when a force F is applied to the flexible substrate 16 in the vicinity of the resistive area 20 urging the flexible substrate 16 carrying the resistive area 20 toward the rigid substrate 12. An actuator 26 is located in register with the aperture 22 and provides a means for application of the force F to urge the flexible substrate 16 carrying the resistive area 20 toward the rigid substrate 12 and its resistive area 18. The actuator 26 is constructed of elastomeric material in order to provide the desired interaction between the resistive areas 18 and 20 as the force F is increased, as will be discussed later.

Figure 2 illustrates, in an exploded view, the registered relation of the flexible substrate 16 with its associated resistive area 20 affixed to the bottom side thereof, the spacer 14 with its associated aperture 22, and the rigid substrate 12 with its associated resistive area 18 affixed to the upper side thereof.

The elastomeric qualities of the actuator 26 provide a key aspect of the operation of the resistive coupling. Figure 4 schematically illustrates the area of contact which occurs between resistive area 18 and resistive area 20 with increasing values of force F. In Figure 4 the resistive area 18 which is affixed to the rigid substrate 12 is shown with a solid line as a substantially circular area. Certainly this area could be other shapes, but a circular area is shown here for sake of discussion. As the force F moves the flexible substrate 16 with the resistive area 20 affixed thereto

toward the rigid substrate 12 and its resistive area 18, an initial contact area 28 is established. Increasing values of the force F operating through the elastomeric actuator 26 will produce, because of the elastomeric qualities of the actuator 26, a spreading area of contact as represented by contact areas 30 and 30' in Figure 4. As this contact area increases, the resistivity of the electrical connection between resistive area 18 and resistive area 20 is reduced and, consequently, the conductivity of that electrical connection is increased. When an electrical potential (not shown) is applied across resistive areas 18 and 20, establishment of a contact area such as areas 28 in Figure 4 would permit a given amount of current to flow between the resistive areas 18 and 20. Increasing the force F and, consequently, increasing the contact area 28 to correspond to contact areas 30 or 30', for instance, would permit a greater amount of current to flow between the resistive areas 18 and 20, which increase in current flow would be proportional to the amount of force F applied to the flexible substrate 16. Thus, the force F is measured in terms of conductivity, and variations in current flow through the resistive areas 18 and 20, which variations in current flow are proportional to variations in the force F, can be processed and evaluated by appropriate circuitry (not shown).

The action of the actuator 26 may be more readily understood by reference to Figure 3 which indicates that the elastomeric qualities of a human finger 30 serve very well to provide a progressive expansion of contact area between resistive areas 18 and 20 with progressively increased amount of force F.

By way of background information, the effect of omitting any spacer means is shown in Figures 5 to 7, which illustrate a resistive coupling 32 including a pair

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of resistive pads 34 and 36. The detail of Figure 5 reveals that the true nature of the surface 38 of the resistive area 34 and the surface 40 of the resistive area 36 is not truly smooth. The surfaces 38 and 40 actually have small peaks 42 which extend above the surfaces 38 and 40. Application of a force through an elastomeric actuator to the resistive coupling 32 results in deflection of the resistive area 34 toward the resistive area 36 as illustrated in Figure 6 to establish an initial contact area in substantially the same manner as was illustrated in Figure 4. A progressively larger value of F would establish a condition similar to that shown in Figure 7, a condition wherein the contact area between the resistive area 34 and the resistive area 36 is enlarged in a manner substantially similar to the manner in which the contact area is increased in Figure 4. The most significant difference between Figure 5 which has no spacer, and Figure 1 which has a spacer 14, is that in Figure 1 when there is no force F applied to the flexible substrate 16 the resiliency of that flexible substrate 16 returns the resistive area 20 to a position of little or no electrical contact with the resistive area 18, depending upon the thickness of the spacer 14, and, consequently, little or no current flow can occur between the resistive areas 18 and 20. In Figure 5, removal of force F results in the flexible substrate 34 resiliently returning to a position with respect to substrate 36 where there must still be some minimal electrical contact between the surfaces 38 and 40 through the various peaks 42 on those two surfaces. External electronic circuitry (not shown) can be designed to establish threshold current values which must be exceeded before the presence of a force is acknowledged.

In Figure 8 a capacitive coupling 44 is comprised of a substrate 46, a substrate 48, a spacer 50 having an

aperture 52, a first capacitive area 54 affixed to the bottom of the substrate 48, and a second capacitive area 56 affixed to the bottom of the substrate 46. Application of a force F to urge the substrate 48 with its capacitive area 54 carried thereon toward the substrate 46 will result in a contact area between the capacitive area 54 and the top of substrate 46 in a manner similar to the spreading contact area discussed in connection with Figure 4 as the force F is increased. The contact area established between the capacitive area 54 and the top of substrate 46 will be substantially parallel with the capacitive area 56 and thereby establish capacitive coupling insofar as portions of capacitive area 54 and capacitive area 56 are in parallel. Increasing force F and thereby increasing the area of capacitive area 54 which is in parallel with capacitive area 56 increases the capacitance of the coupling 44 and, consequently, when a potential is applied across the capacitive areas 54 and 56, appropriate external electronic circuitry (not shown) can detect such changes in capacitance, which changes in capacitance are proportional to the amount of force F applied to the substrate 48.

Figure 9 illustrates an arrangement utilising an inductive coupling. Figure 9 illustrates a top view of a substrate 58 with a generally spiral-shaped inductive element 62 affixed to the top of the substrate 58. Application of a force F (not shown) to a substrate located above the substrate 58 and with a resistive area affixed to the bottom thereof will produce a contact area 60 as shown in Figure 9. The contact area 60 serves to short out a portion of the spiral-shaped inductive element 62 thereby reducing the inductance of inductive element 62.

Increasing the force F over the amount of force F depicted in Figure 9 produces an increased contact area 60', as shown in Figure 10. Contact area 60' serves to short out a larger portion of the inductive element 62, thereby further reducing the inductance of inductive element 62. The variance of inductance occasioned by the spreading contact area 60 with increased force F will vary proportionally with the force F .

In Figure 11, the spacer and the flexible substrate are incorporated into one structure in that the flexible substrate 64 has moulded therein a plurality of protuberances 66, which protuberances contain electrically propertied areas 68. The electrically propertied areas 68 are so generally described since they can be resistive, capacitive, or inductive. Application of a force F against a protuberance 66 urges the protuberance 66, carrying its respective electrically propertied area 68, toward the other substrate of the device (not shown) to effect operation as previously described. The protuberances 66 are moulded so as to be resilient and to return to their original protuberant position upon removal of the force F .

In Figure 12, a flexible substrate 70 has moulded therein inverse protuberances 72. Electrically propertied areas 74 are affixed to the underside of the flexible substrate 70 intermediate the inverse protuberances 72 so that application of a force F to an area intermediate the inverse protuberances 72 will urge an electrically propertied area 74 toward the second substrate of the device (not shown) and effect operation in the manner described previously. The inverse protuberances 72 are moulded in a manner whereby they are resilient so that they will return to their normally protuberant positions upon removal of the force F .

CLAIMS

1. A force measuring device comprising a first electrically propertied means and a second electrically propertied means, said first means being disposed in proximate relationship with said second means and responsive to a force moving said first means with respect to said second means to vary an electrical property of said device proportionally to said force; said second means being a substantially rigid non-conductive substrate with electrically propertied lands affixed thereto, and said first means being a substantially flexible non-conductive substrate with electrically propertied lands affixed thereto;

said device further comprising spacer means disposed intermediate said first means and said second means to maintain, in an at rest position, said first means and said second means in spaced, substantially parallel relationship; said spacer means having a plurality of apertures therethrough; said apertures allowing electrical communication therethrough between said electrically propertied lands of said first means and said electrically propertied lands of said second means; and

said device further comprising means for applying said force to said first means, said means for applying said force comprising a plurality of actuators carried upon a common actuator assembly, said plurality of actuators being capable of selectively impinging upon various areas of said first means in register with said apertures.

2. A device according to claim 1, wherein said plurality of actuators equals said plurality of apertures.



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3. A device according to claim 2, wherein each of said plurality of actuators is in register with one of said plurality of apertures.

4. A device according to claim 3, wherein said
5 actuators are capable of impinging upon more than one area of said first means simultaneously.

5. A force measuring device comprising a first non-conductive substrate, a second non-conductive substrate, an actuator means and a spacer means;
10 said first substrate being substantially flexibly resilient and having a first plurality of electrically resistive lands affixed thereto; said second substrate being substantially rigid and having a second plurality of electrically resistive lands affixed thereto; said
15 spacer means being intermediate said first substrate and said second substrate and, in an at rest position, maintaining said substrates in spaced, substantially parallel relation; each of said first plurality of resistive lands being in facing relation with and in
20 register with one of said second plurality of resistive lands, said spacer means having a plurality of apertures therethrough, each of said plurality of apertures being in register with one of said first plurality of resistive lands; said first substrate being responsive to a force
25 moving said first substrate with respect to said second substrate, through one or more of said apertures, to vary the conductivity of said device proportionally to said force;

said actuator means being capable of applying said
30 force to said first substrate and comprising a plurality of elastomeric actuators, a common actuator carrier and a common control means; each of said plurality of actuators being in register with one of said first plurality of resistive lands, each of said actuators
35 being connected to said common actuator carrier, and said



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common actuator carrier being connected to and responsive to said common control means.

6. A device according to claim 5, wherein said actuator means further comprises a Z-control means and a Z-actuator; there being an additional aperture through said spacer means, and additional electrically resistive lands affixed to said first and second substrates, associated with and in register with said Z-actuator; said Z-control means being connected to said Z-actuator and operable independently from said common control means.

7. A force measuring device substantially as hereinbefore described with reference to Figure 13, or Figure 14, of the accompanying drawings.

