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[54] FORCE-TO-SIGNAL CONVERTER

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[21] Appl. No.: **98,268**

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Jan. 27, 1970	Japan	45/7533

[52] **U.S. Cl.** .....**73/398 R,** 73/407 R

[51] **Int. Cl.**.....**G01l 7/08,** G01l 9/10

[58] **Field of Search**.....73/407, 388 B, 398 R, 410

[56] **References Cited**

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Primary Examiner—Donald O. Woodiel

Attorney—Hill, Sherman, Meroni, Gross & Simpson

[57] **ABSTRACT**

A force-to-signal converter having a device for receiving an external force, a device for transmitting the external force, a third device for converting the external force delivered from the second-mentioned device into a corresponding deflection, and a device for converting the deflection obtained from the third-mentioned device into a signal, in which the third-mentioned device is a substantially E-shaped spring.

7 Claims, 19 Drawing Figures

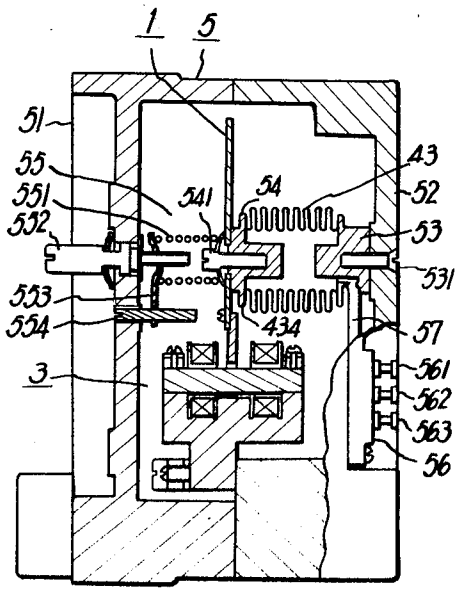


Fig. 1

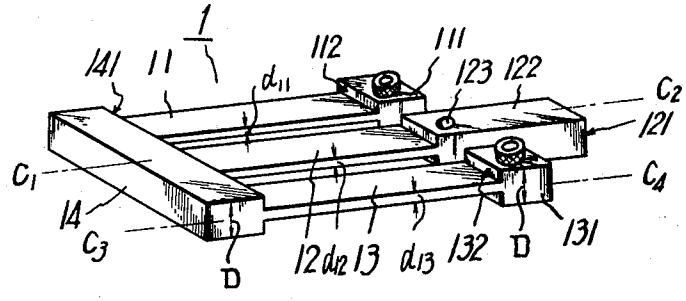
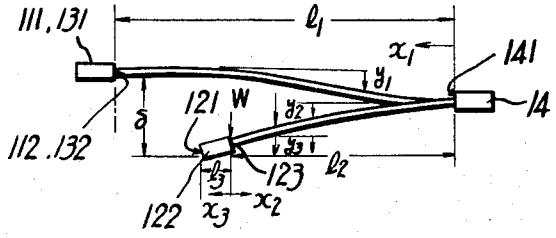


Fig. 2



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Fig. 3A

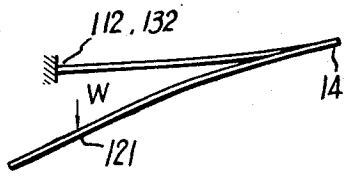


Fig. 3B

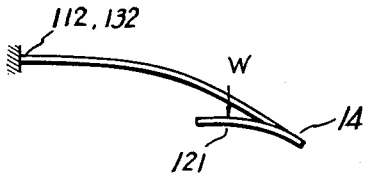


Fig. 3C

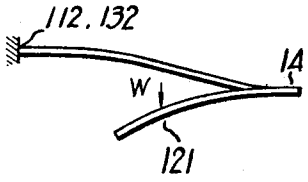


Fig. 3D

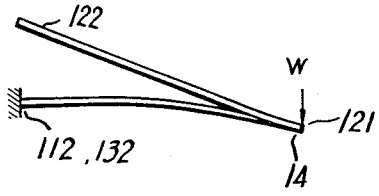
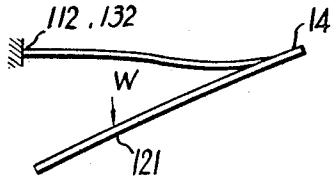


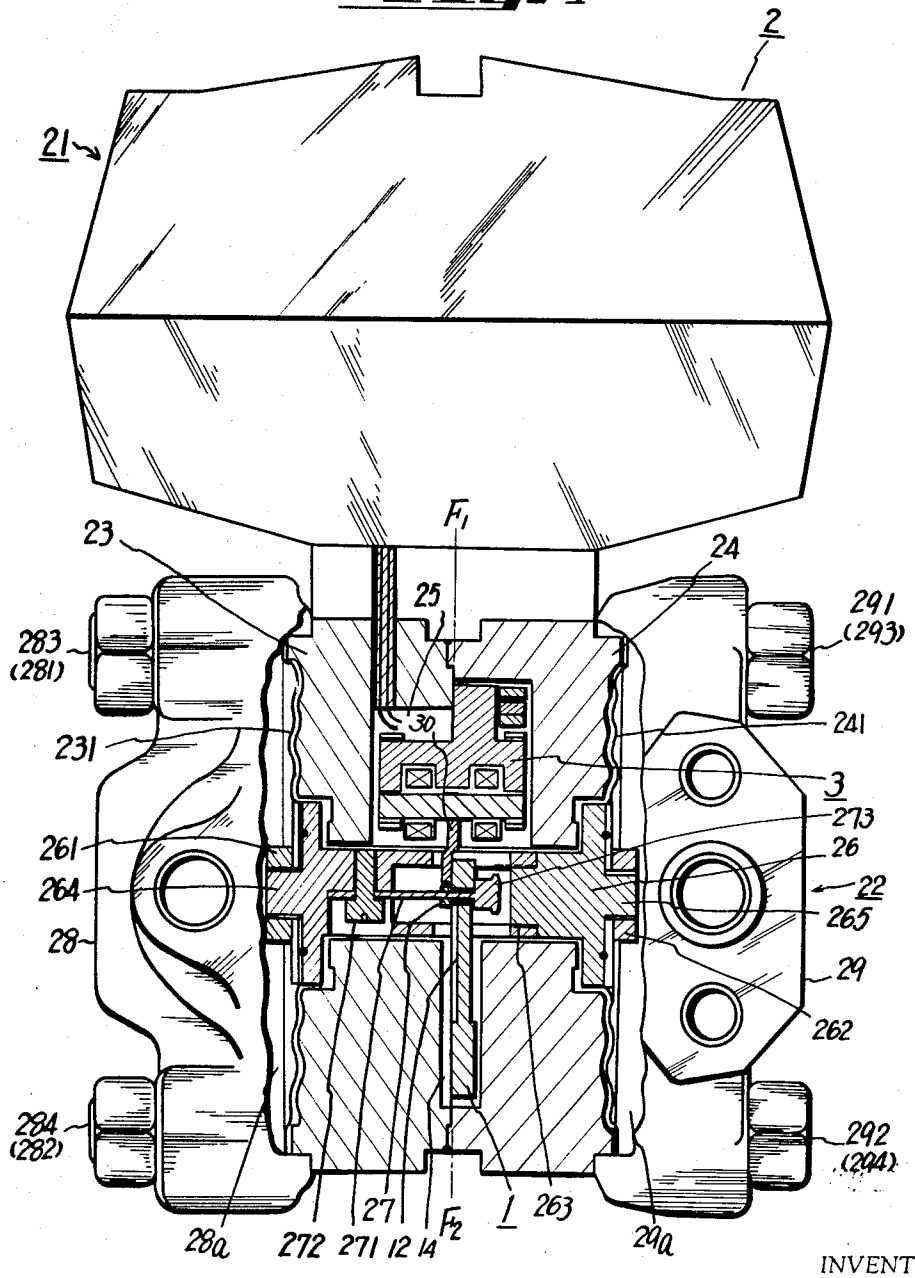
Fig. 3E



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Fig. 4



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Fig. 5

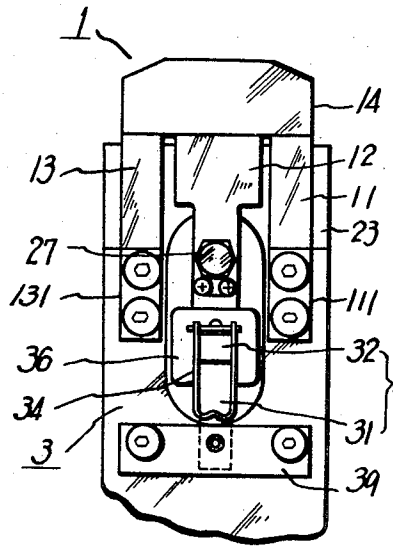
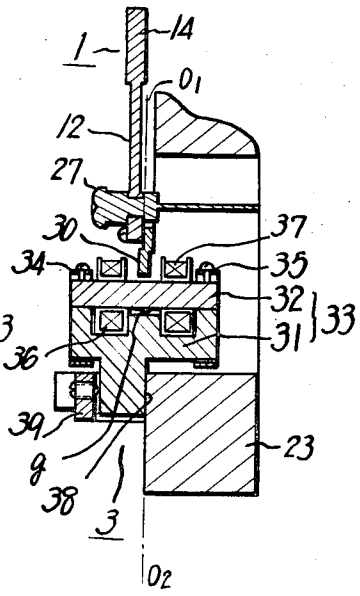


Fig. 6



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Fig. 7

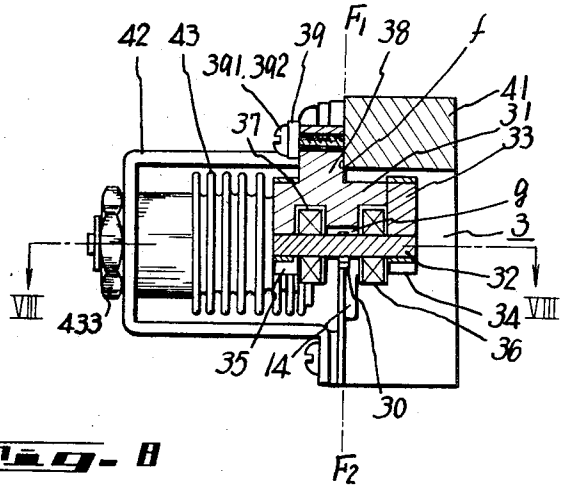


Fig. 8

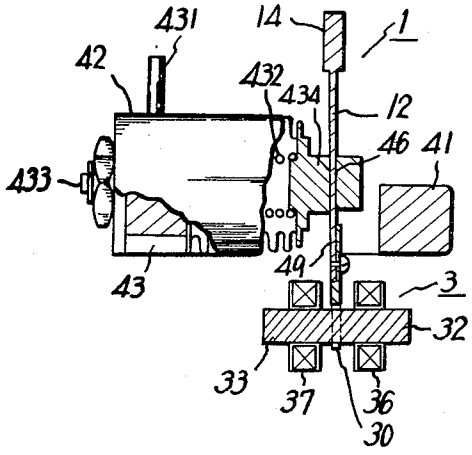
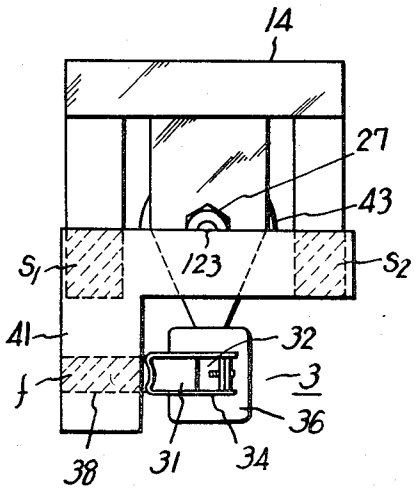


Fig. 9



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Fig. 10

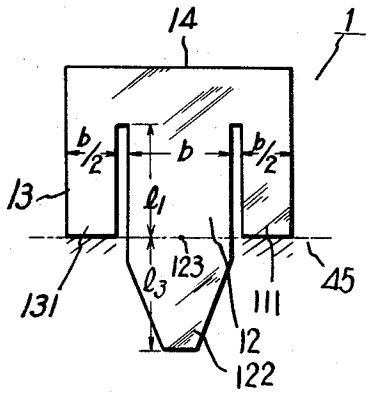


Fig. 11

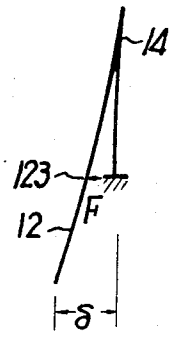
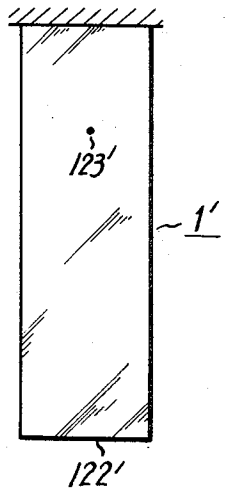


Fig. 12



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Fig. 13

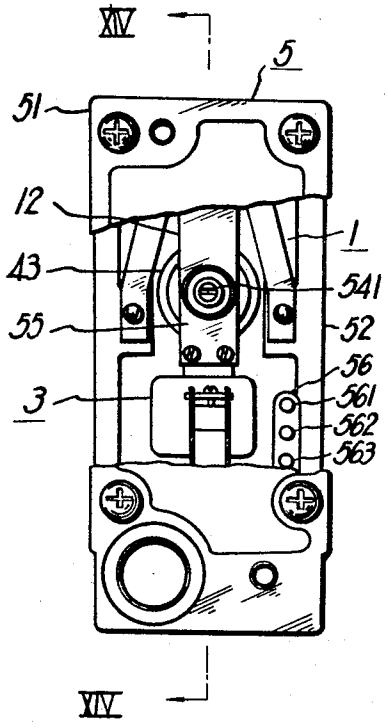
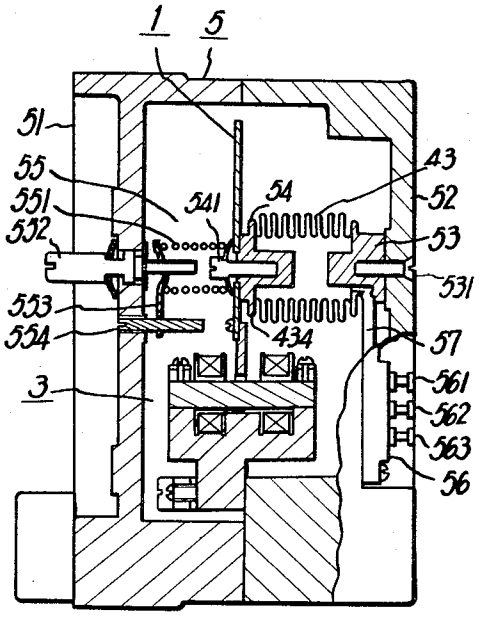


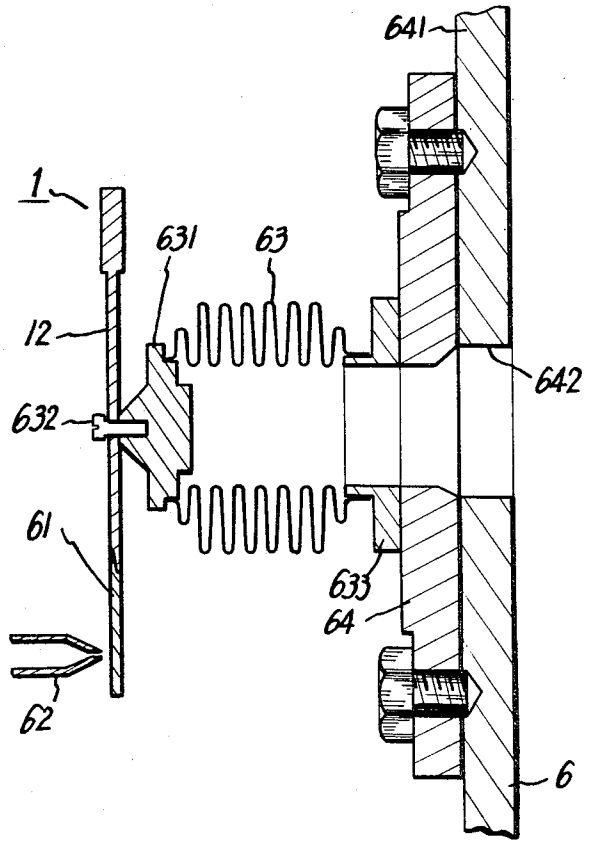
Fig. 14



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Fig. 45



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FORCE-TO-SIGNAL CONVERTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a force-to-signal converter, and more particularly to a force-to-signal converter for converting a force into an electric or air pressure signal corresponding thereto as is the case with a differential pressure detector, a pneumatic-to-current converter, a liquid level transmitter or the like.

2. Description of the Prior Art

A known differential pressure detector for measuring the flow quantity of a fluid is of the type in which a differential pressure generating means such as an orifice is provided in the passage of the fluid to be measured, pressures on both sides of the orifice are received by two interconnected diaphragms and a differential pressure (a force) therebetween is applied to a rod to equibrate it with the force of a control spring, thereby producing an electric or air pressure signal corresponding to the aforementioned flow quantity of the fluid. Such a conventional differential pressure detector has disposed therein the control spring and utilizes it for achieving force or displacement balance as above described. While, a prior art pneumatic differential pressure detector converts a differential pressure detected at a detecting end into an air pressure signal and transmits it to a control chamber or the like. This pneumatic differential pressure detector is often used for explosion-proof instrumentation or in the event that an air pressure source is located in its vicinity to allow easy use of air pressure. In some cases, however, an air pressure signal (0.2 to 1.0 Kg/cm^2) picked up by such pneumatic differential pressure detector as above described is further converted into a rated electric signal (of, for example, 10 to 50 mA), in which case the pneumatic-to-current converter is employed. Where the aforementioned differential pressure detector, pneumatic-to-current converter or like device for converting a force into an electric or air pressure signal employs many components such as springs, links, levers or the like for transmitting a force or deflection, the manufacturing process increases with the number of the components to raise the manufacturing cost. Further, when the number of the components is great, clearances between the components accumulate, so that the number of the components is preferred to be small from the viewpoint of precision, too. In a deflection type device for picking up a differential pressure or the like in the form of a deflection, expansion or shrinkage of the components resulting from temperature change causes zero shift to introduce errors in measured values and incomplete fixing of the springs or links also leads to errors. In addition, uaual differential pressure detectors range from those for low-pressure use as of 5 Kg/cm^2 to those for high pressure use as of 500 Kg/cm^2 or more, and hence are inevitably bulky.

SUMMARY OF THE INVENTION

One object of this invention is to provide a force-to-signal converter with a substantially small spring which is suitable for use in the differential pressure detector, pneumatic-to-current converter or like device for converting a force into an electric or air pressure signal.

Another object of this invention is to provide a highly accurate and strong force-to-signal converter which employs a substantially E-shaped spring and is adapted to reduce to zero the bending moment of the E-shaped spring at the point fixed to a member, thereby to eliminate hysteresis thereof.

Another object of this invention is to provide a force-to-signal converter which employs a substantially E-shaped spring and in which the relation between a first lever (that portion of the E-shaped spring extending from a fixed point to the base thereof) and a second lever (that portion of the spring extending from the base to a loading point) is suitably selected to permit lateral movement of a loading portion or the base irrespective of the value of a load.

Another object of this invention is to provide a force-to-signal converter which employs a substantially E-shaped spring and in which the free ends of both side legs of the E-shaped spring are fixed to a member to be fixed to facilitate fixing the fixed portion of the side legs of the spring in the same plane, thereby preventing non-linearity errors due to torsions resulting from a lag in the fixed faces of the legs and temperature change.

Another object of this invention is to provide a force-to-signal converter which employs a substantially E-shaped spring to reduce the number of components to thereby prevent errors due to accumulation of clearances between the components, simplify the construction of the converter, reduce troubles and decrease its manufacturing cost.

Still another object of this invention is to provide a force-to-signal converter which employs a substantially E-shaped spring and in which reference planes are provided in components of the converter and in a member to be fixed, thereby to eliminate errors in measured values resulting from thermal expansion and contraction of the components due to temperature change.

Other objects, features and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view showing one example of a force-to-deflection converter for use in a force-to-signal converter apparatus of this invention;

FIG. 2 is a schematic diagram, for explaining the general operation of the force-to-deflection converter depicted in FIG. 1;

FIG. 3A to 3E are schematic diagrams, for explaining operations of the force-to-deflection converter under various conditions;

FIG. 4 illustrates, partly in cross-section, one embodiment of the force-to-signal converter apparatus of this invention;

FIG. 5 shows a force-to-current converter employed in the apparatus of FIG. 4;

FIG. 6 is a right side cross-sectional view of the converter depicted in FIG. 5;

FIG. 7 shows a modified form of the apparatus of this invention;

FIG. 8 is a cross-sectional view taken along the line VIII—VIII in FIG. 7;

FIG. 9 is a right-hand side view of the apparatus depicted in FIG. 7;

FIG. 10 is a plan view of a force-to-deflection converter employed in the apparatus of FIG. 7;

FIG. 11 is a schematic diagram, for explaining the operation of the force-to-deflection converter of FIG. 10;

FIG. 12 schematically shows the relative size of a contilever having the same characteristics as those of the force-to-deflection converter depicted in FIG. 10;

FIG. 13 illustrates another modification of the apparatus of this invention improved from that of FIG. 7;

FIG. 14 is a cross-sectional view taken along the line XIV—XIV in FIG. 13; and

FIG. 15 is an explanatory diagram of a further modification of this invention as applied to a liquid level measuring instrument.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 reference numeral 1 indicates generally a spring constituting a force-to-deflection converter employed in the force-to-signal converter of this invention, which spring 1 consists of three legs 11, 12 and 13 and a base 14 arranged in substantially E-shaped configuration. It is preferred to form the spring 1 of a precipitation hardening alloy such as Span C, Sumi Span EL-3 or Ni-Span C (Registered Trademarks) each of which is low in the temperature coefficient of elasticity. Reference numerals 11.1 and 131 designate fixed portions formed at the free ends of the side legs 11 and 13 and inner end faces 112 and 132 of the fixed portions 111 and 131 form vertical fixed planes. At the free end of the central leg 12 a loading member 123 having a deflection point 121 is provided. The spring 1 is formed by cutting from a homogeneous sheet metal in such a manner as to be symmetrical with respect to a vertical plane passing the center line C_1—C_2 of the central leg 12 in two dimensions and with respect to a horizontal plane crossing the vertical plane at right angles thereto and passing the center line C_3—C_4 of the spring 1 in three dimensions. In this case, the thicknesses d_{11}, d_{12} and d_{13} of the central resilient portions of the three lets 11, 12 and 13 are selected far smaller than the width D of the other portions 14, 111, 122 and 131.

A description will hereinbelow be given of basic equations in the calculation of the characteristics of the spring 1 of the above construction. Let it be assumed that moment of inertia I in the section of each resilient portion is constant throughout it, and that the base 14 having extended therefrom the legs is rigid. Those portions of the legs 11 and 13 extending from the fixed points 112 and 132 to the inner side face 141 of the base 14 the portion of the central leg 12 extending from the inner side face 141 to a loading point 123 and the portion from the loading point 123 to the deflection point 121 will hereinafter be referred to as first levers, a second lever and a loading area l_3 respectively. Moment, curvature, gradient and deflection in the above levers and the loading member 122 are obtained as follows (refer to FIG. 2).

1. First levers

$$M_1 = W(x_1 - l_1) \tag{1.1}$$

$$d^2y_1/dx_1^2 = -(W/EI)(x_1 - l_2) \tag{1.2}$$

$$dy_1/dx_1 = -W/EI\,[(x_1^2/2) - l_2x_1 + l_1(l_2 - l_1/2)] \tag{1.3}$$

$$y_1 = -W/EI\,[(x_1^3/6) - (l_2/2)x_1^2 + l_1(l_2 - l_1/2) + l_1^2(l_1/3 - l_2/2)] \tag{1.4}$$

2. Second lever

$$M = Wx_2 \tag{2.1}$$

$$d^2y_2/dx_2^2 = -(W/EI)x_2 \tag{2.2}$$

$$dy_1/dx_1 = -W/EI\,[(x_1^2/2) - l_2x_1 + l_1(l_2 - l_1/2)] \tag{2.3}$$

$$y_2 = W/EI\,[x_2^3/6 + (l_1^2/2 - l_1l_2 - l_2^2/2)x_2 + l_2^3/3 - l_1^2l_2/2 + l_1l_2^2)] \tag{2.4}$$

3. Loading member 122 (l_3)

$$dy_3/dx_3 = (l_1^2/2) - l_1l_2 - (l_2^2/2) \tag{3.1}$$

$$y = [(l_1^2/2) - l_1l_2 - (l_2^2/2)]x_3 \tag{3.2}$$

W : the load applied to the deflection point 122 3

l_1, l_2 and l_3: Lengths (mm.) of the first and second levers and the loading member 122

M_1 and M_2 : Moment (Kg/mm.) applied to the first and second levers

x_1 : co-ordinates (mm.) of a point on the first lever with the inner side face 141 of the base 14 being as origin

x_2 : co-ordinates (mm.) of a point on the second lever with the loading point 123 being as origin

x_3 : co-ordinates (mm.) of a point on the loading member 122 with the loading point 123 being as origin

y_1 : co-ordinates (mm.) of points on the first levers toward the direction of the force applied to the lever with the fixed points 112 and 132 being as origins

y_2 : co-ordinates (mm.) of a point on the second lever toward the direction of the force applied to the lever with the inner side face 141 being as origin

y_3 : co-ordinates (mm.) of a point on the loading member 122 forward the direction of the force applied to the lever with the loading point 123 being as origin

E : Young's modulus of the spring material

4. From the above equations the total amount of deflection δ of the deflection point 121 caused by the load W is given by the following equation.

$$\delta = y_1 + y_2 + y_3 \tag{4.1}$$

$$= -W/EI\,[(l_1^3/3 - l_1^2l_2 + l_1l_2^2 = l_2^3/3) - l_3(l_1^2/2 - l_1l_2 - l_2^2/2)] \tag{4.2}$$

5. If the section modulus is taken as Z, the bending stresses σ_1 and σ_2 of the first and second levers are as follows :

$$\sigma_1 = W(l_1 - l_2)/Z \text{ or } Wl_2/Z \tag{5.1}$$

$$\sigma_2 = Wl_2/Z$$

6. Further, a lever ratio L which is a ratio of the deflection of the loading point 123 to that of the deflection point 121 is given by the following equation.

$$L=\frac{\left(\frac{l_1^3}{3}-l_1^2l_2+l_1l_2^2+\frac{l_2^3}{3}\right)-l_3\left(\frac{l_1^2}{2}-l_1l_2-\frac{l_2^2}{2}\right)}{\frac{l_1^3}{3}-l_1^2l_2+l_1l_2^2+\frac{l_2^3}{3}} \quad (6.1)$$

Based upon the foregoing basic equations, equations for the calculation of the characteristics of the spring **1** under various particular conditions are as follows :

a. When the moments at the fixed points **112** and **132** are zero, stresses at these fixed points of the first lever are zero, and accordingly l_2 is selected such that $\sigma=0$.

From the equation (5.1),

$$\sigma_1=W/Z\,(l_1-l_2)=0 \quad (a.1)$$

$$l_1=l_2 \quad (a.2)$$

The load-deflection characteristic in this case is as follows :

$$\delta=-W/EI\,l_2{}^2(2/3\,l_2+l_3) \quad (a.3)$$

b. When the gradient of the spring at the loading point **123** is zero, the deflection of the loading point **123** is the same as that of the deflection point **121**, namely the lever ratio L is 1, so that the following equation is given from the equation (6.1),

$$l_2=(1/1+\sqrt{2})l_1 \quad (b.1)$$

The load-deflection characteristic in this case is given by the following equation (*b*.2).

$$\delta=-(W/EI)\cdot \tfrac{2}{3}l_2{}^3 \quad (b.2)$$

where δ is a deflection of the deflection point **121**.

c. When the gradient of the base **14** is zero, if $x_1=0$ and $dy_1/dx_1=0$ in the equation (1.3),

$$l_2=\tfrac{1}{2}\,l_1 \quad (c.1)$$

The load-deflection characteristic is given as follows :

$$\delta=-(W/EI)\,l_2{}^2[l_2+(l_3/2)] \quad (c.2)$$

As will be apparent from the foregoing equations (*a*.1) and (*a*.2), the bending moments at the fixed points **112** and **132** can be reduced to zero by locating the fixed points **112** and **132** and the loading point **123** on the same straight line, namely by selecting the lengths of the first and second levers to be equal to each other. Accordingly, it is possible to provide a force-to-deflection converter which has no hysteresis and is highly accurate and mechanically strong. Further, if the length of the second lever is selected to be $1/1+\sqrt{2}$ or 1/2 of that of the first lever, the loading member **122** or the base **14** can be always moved in parallel (refer to the equations (*b*.1) and (*c*.1) irrespective of the value of the load *W*. In addition, the spring **1** is simple in shape (a plane shape) and the fixed points **112** and **132** can be readily located on the same plane, so that it is possible to remove torsion resulting from lag of the positions of the fixed points and deformation caused by temperature change. Moreover, since the spring **1** is E-shaped, its effective length can be increased, as compared with its size and this enables substantial reduction in size of the force-to-deflection converter.

FIGS. 3A to 3E are schematic diagrams for explaining the operations of the spring in those cases in which the moments at the fixed points **112** and **132** are reduced to zero by selecting l_1 to be equal to l_2, in which the gradient at the loading point **123** is reduced to zero by selecting l_2 to be $(1/1+\sqrt{2})\,l_1$, in which the gradient at the inner side face **141** of the base **14** is reduced to zero by selecting l_2 to be $l_1/2$, in which $l_2=0$ and a load is applied to the base **14** and in which $l_2=\frac{2}{3}l_1$ and the base **14** does not deflect irrespective of the value of a load.

With reference to the drawings a description will be given in connection with various devices of this invention employing the aforementioned spring as a force-to-deflection converter for converting a force into an electric or air pressure signal.

FIG. **4** illustrates one embodiment of the device of this invention for converting a force into an electric or air pressure signal. FIG. **5** is a schematic diagram for explaining the construction of a force-to-current converter employed in the device of FIG. **4** and FIG. **6** is a right side cross-sectional view of the converter depicted in FIG. **5**. In those figures, reference numeral **2** indicates a device proper, which consists of an upper housing **21** for enclosing therein an amplifier or the like and a lower housing **22**. Reference numerals **23** and **24** designate two ring-shaped blocks constituting the principal part of the lower housing **22**. The outer sides of the blocks **23** and **24** have attached thereto thin disc-shaped diaphragms **231** and **241** along their outer peripheries serving as pressure receiving elements and are formed with carrugations corresponding to the diaphragms **231** and **241**. The two blocks **23** and **24** are formed as a unitary structure by welding together the outer peripheral portions of their opposing faces and a room **25** of a suitable shape is formed in the inner opposing faces. Reference characters F1–F2 indicate a reference plane described later, which is formed on the one block **23** facing the room **25**. Reference numeral **26** designates a movable rod, which is movably disposed in a bore formed centrally of the blocks **23** and **24** and is fixed at both ends to the diaphragms **231** and **241** by means of welding and screws **261** and **262**. Further, the movable rod **26** consists of two members **264** and **265** coupled together by a screw **263** and the left-hand member **264** is formed partly hollow. Reference numeral **1** identifies the spring described above and **27** a coupler for coupling the spring **1** and the movable rod **26**. The coupler **27** is located in the hollow of the movable rod **26**. The leg portion **271** of the coupler **27** is made to be a thin plate which, in turn, is fixed to the left side of the movable rod **26** by means of a screw **272**. The spring **1** is substantially E-shaped as depicted in FIG. **1** and the free ends of the both side legs **11** and **13** of the both side legs **11** and **13** of the spring **1** are closely fixed to the block **23** and the head of the coupler **27** is fixed to the central leg **12** at its intermediate portion. The top end of the central leg **12** of the spring **1** has mounted thereon a short-circuiting ring **30** for changing the inductance of a differential inductor which will hereinbelow be described. The short-circuiting ring **30** shifts laterally in response to the differential pressure between those applied to the diaphragms **231** and **241**. Reference numeral **3** designates a differential inductor, which is made up of a core **33** consisting of a substantially E-shaped core member **31** and a rod-like core member **32**, fixtures **34** and **35** for fixing the members **31** and **32**, a pair of same coils **36** and **37** wound on the core member **32** and the

aforementioned short-circuiting ring **30** made of copper and disposed in a flux gap *g* as shown in FIG. **6**. Reference numeral **38** identifies a fixing face flush with a reference plane O_1–O_2 of the core **33** and the differential inductor **3** is secured to the aforementioned block **23** by means of a coupling piece **39** utilizing the face **38**. In this case, the fixing face **38** of the differential inductor **3**, the reference plane O_1–O_2 of the core **33** passing through the center of the flux gap *g* and the fixed faces **111** and **131** of the spring **1** agree with the reference plane F1–F2 of the block **23**. Reference numerals **28** and **29** indicate plates respectively secured to both sides of the blocks **23** and **24** by four bolts **281** to **284** and **291** to **294** (shown in FIG. **4**). The plates **28** and **29** and the diaphragms **231** and **241** respectively define pressure receiving chambers **28a** and **29a** therebetween, into which pressures to be measured are respectively introduced from the outside. Reference numerals **201** and **202** indicate lead wires for the coils **36** and **37**, the lead wires **201** and **202** being connected to, for example, terminals (not shown) in the upper housing **21** through an aperture bored in the block **23** in a manner of hermetic seal. The defferential inductor **3** constitutes a deflection-to-current converter for converting the deflection of the spring **1**, namely the amount of deflection of the short-circuiting ring **30** into a corresponding electric signal.

With such an arrangement as sbove described, when the pressure to be measured are introduced into the pressure receiving chambers **28***a* and **29***a* a differential pressure therebetween is applied to the diaphragms **231** and **241** to shift the movable rod **26** laterally. The differential pressure applied to the movable rod **26** acts on the central leg **12** of the spring **1** through the coupler **27** to deflect the short-circuiting ring **30** to a equibrium point of the differential pressure with resiliency of the spring **1** in accordance with the lever ratio dependent upon the shape of the spring **1**. In response to the deflection of the short-circuiting ring **30** the inductances of the coils **36** and **37** of the differential inductor **3** vary, in which case, by controlling the sum of currents flowing in the coils **36** and **37** constant, a differential current is caused to correspond to the amount of deflection of the short-circuiting ring **30**. Accordingly, an electric signal corresponding to the differential pressure can be transmitted by amplifying an output current of the differential inductor **3**.

In such deflection type instruments as above described, expansion or shrinkage of the components resulting from temperature change causes zero shift or the like and leads to errors in measurement. Especially, thermal expansion of the components caused by temperature change greatly affects the precision of such a minute deflection type instrument of this invention (commonly called "FULL SPAN", because the deflection range of the short-circuiting ring is about 0.03 to 1.18 and is extremely minute). Accordingly, special regard must be paid to the method of fixing the components therebetween, the selection of the reference planes and so on.

The influence of the thermal expansion in the foregoing example will hereinbelow be made.

1. Coefficients of linear expansion of the respective components (in mm/°C)
   a. Blocks **23** and **24**
      Rustless steel 316 (AISI—17.3×10^{-6}
   b. Spring **1**
      Ni-Span C (trademark) — 8×10^{-6}
   c. Short-circuiting ring **30**
      — 1.65×10^{-6}
   d. Core **33**
      Ferrite — 9×10^{-6}
2. Amounts of deflection of the respective elements at positions 1 mm away from certain reference planes when temperature changes from 20° to 120°C.
   a. Blocks **23** and **24** — 17.3μm (microns)
   b. Spring **1** — 8μm
   c. Short-circuiting ring **30** — 16.5 μm
   d. Core **33** — 9μm
3. In the foregoing example the deflection range of the short-circuiting ring **30** is selected to be about 0.3 to 1.18 mm. as previously described. The deflection range of the short-circuiting ring **30** in practice is usually about 0.05 mm. The ratios of the amounts of deflection caused by thermal expansion mentioned in (2) to the deflection range 0.05 mm are as follows:
   a. Blocks **23** and **24** — 3.4%
   b. Spring **1** — 1.6%
   c. Short-circuiting ring **30** — 3.3%
   d. Core **33** — 1.8%
4. The above ratios directly affect the accuracy of the instrument. Accordingly, the accuracy of the instrument greatly lowers in the cases where the components are secured to fixed members of different coefficients of expansion or the fixed faces of the components lie in quite different planes.

In the instrument of this invention, a differential pressure applied to the movable rod is converted into a deflection through the spring small in size and simple in construction and the deflection is directly converted by the deflection-to-current converter into an electric signal, so that no error is caused by the accumulation of clearances between the components. Further, since the components constituting the spring and the deflection-to-current converter are extremely small in number, the instrument of this invention is simple in construction, free from troubles and low in manufacturing cost. In addition, the reference planes, are provided in the spring and the deflection-to-current converter at predetermined positions and the components are formed as a unitary structure utilizing the reference planes, so that the accuracy of the instrument is not a bit affected by the thermal expansion of the components due to temperature change. Moreover, the spring and the deflection-to-current converter are housed in the blocks and only electric leads are led out from the housings and this eliminates the necessity of a complicated seal device.

FIG. **7** is a schematic diagram, for explaining a modified form of the instrument of this invention, FIG. **8** is its cross-sectional view taken along the line VIII—VIII. FIG. **9** is a right side view of the instrument depicted in FIG. **7**. In these Figures reference numeral **41** indicates a member to be fixed such, for example, as a housing or the like, **42** a frame of a substantially U-shaped cross-section fixed to the member **41** and **43** bellows mounted in the frame **42** and serving as a pressure receiving element. Reference numeral **431** designates an air pressure inlet pipe of the bellows **43**, **432** a spring for adjustment of the zero point of the bel-

lows 43 and 433 its adjustment crew. Reference numeral 1 identifies a spring identical in construction with the aforementioned one and consisting of legs 11, 12 and 13 and a base 14 and the free ends 111 and 131 of the side legs 11 and 13 are fixed to the aforementioned member 41. In this case, the both free ends 11 1 and 131 are fixed to lie on a straight line parallel with the leg 11 as indicated by a one-dot chain line in FIG. 10. Further, a movable and 434 of the bellows 43 is secured to the intermediate portion of the central leg 12 of the spring 1. The central point 46 (the loading point 123 of the spring 1) of the portion having secured thereto the movable end 434 is selected to agree with the aforementioned line 45. Reference numeral 3 represents a differential inductor, which is identical in construction with that previously described in connection with FIGS. 4, 5 and 6. A short-circuiting ring 30 of the differential inductor 3 is secured to the tip 122 of the central leg 12 of the spring 1. A face *f* of a leg 38 of a core 33 is selected to be flush with a reference plane C of the core 33 passing through the center of the deflection range of the short-circuiting ring 30 and the differential inductor 3 is fixed by screws 391 and 392 to the member 41 through a coupling piece 39, with the face *f* being urged against the member 41. When the short-circuiting ring 30 shifts, the inductances of the coils 36 and 37 changes and output signals are derived from their output ends corresponding to the amount of deflection of the short-circuiting ring 30. In the member 41 a reference plane F1–F2 is provided (refer to FIG. 4) and the components are assembled together in such a manner that the aforementioned face *f*, the reference plane *c* and fixed faces s_1 and s_2 of the spring 1 may agree with the reference plane F1–F2.

A description will herein below be given of the operation of the instrument of this example. Assume that a reference position is such a position at which a constant air pressure (including zero) sealed in the bellows 43 is in equilibrium with the force of the spring 432 and the short-circuiting ring 30 lies in the reference plane *c* of the core 33. When the air pressure introduced into the bellows 43 through the inlet port 431 increases, the movable end 434 of the bellows 43 shifts to right in FIG. 8. At this time, a force F is applied to the central leg 12 of the spring 1 to deform it as shown in FIG. 11, thereby to shift the short-circuiting ring 30.

If the effective lengths of the both side legs 11 and 13 (first levers) of the spring 1 are taken as l_1 and the length of the central leg 12 (second lever) from the loading point 123 to the short-circuiting ring 30 is taken as l_3, the amount of deflection of the short-circuiting ring 30 is given by the following equation.

$$8l_1^3/Ebh^3\,[(1+(3/2)\cdot(l_3/l_1)\,]F \qquad (d)$$

where E is Young's modulus of the spring 1, h the thickness of the effective portion of the spring 1 (uniform) and b the width of the central leg 42 of the spring 1 (the widths of the both side legs 11 and 13 being $b/2$.

With the deflection of the short-circuiting ring 30, the inductances of the coils 36 and 37 vary and an output signal is derived from an output terminal of the differential inductor 3 in response to the aforementioned input air pressure.

The instrument of the present example is different from that of FIG. 4 in that an air pressure is introduced into the bellows 43 and a force produced therein is converted into an electric signal. Generally, the resilient characteristic of the bellows such as above described is nonlinear but in the present invention the small deflection range of the loading point can be utilized by making use of the force-to-deflection converter made up of a substantially E-shaped spring, so that the linearity of the resilient characteristic is very excellent. As will be apparent from the equation (*d*), the lever ratio is $[1+(3/2)\cdot(l_3/l_1)\,]$ and even if $l_1 = l_3$, this can be magnified up to 2.5 times, so that the lever ratio is relatively great for the size of the instrument, which can be formed simple in construction and small in size.

FIG. 12 shows a cantilever of actual size which performs the same deflection as the spring of FIG. 10 when made with the same thickness and subjected to the same maximum stress and load. In FIG. 12 reference numerals 1′, 123′ and 122′ represent he elements corresponding to those 1, 123 and 122 shown in the foregoing examples.

FIG. 13 is a schematic diagram, for explaining the construction of another modification of the instrument for converting a force into an electric signal which is formed by improving one part of the instrument exemplified in FIG. 7 and FIG. 14 is a cross-sectional view taken along the line XIV—XIV in FIG. 13. In the FIGS. 13 and 14, reference numeral 5 indicates a rectangular housing, which consists of two members 51 and 52 which may be separated at the center in FIG. 14. The housing 5 has enclosed therein the aforementioned bellows 43 serving as a force generating means, a force-to-deflection converter 1 made up of a substantially E-shaped spring and a deflection-to-current converter 3 made up of a differential inductor. Reference numeral 53 designates a mounting base for fixing the bellows 43 to the right-hand housing member 52 through a screw 531 and 54 a mounting base for fixing a movable end 434 of the bellows 43 to the central leg 12 of the spring 1 by means of a screw 541. Reference numeral 55 identifies a zero adjustment mechanism for the bellows 43, 551 a coiled spring, 552 a rotatable adjustment member, 553 a plate fixed to the coiled spring 551 threadably engaged with the adjustment member 552 and 554 a stop pin engaging the plate 553 for preventing its rotation. Reference numeral 56 indicates a terminal board having electric terminals 561 to 563 and 57 an air pressure supply pipe for introducing an input air pressure into the bellows 43. The elements such as the spring 1, the differential inductor 3 and so on are identical in construction with those previously described with FIG. 7 and the instrument made up of these elements for converting a force into an electric signal operates in substantially the same manner as that previously described and achieves the same object and effect. The instrument of the present example is featured in that the zero adjustment mechanism 55 is placed opposite the movable end 434 of the bellows 43, as compared with the instrument of FIG. 7 in which the zero adjustment mechanism is disposed in the bellows 43. This construction greatly facilitates assembling of the instrument and zero adjustment.

FIG. 15 is a schematic diagram, for explaining the construction of another modification of this invention.

In the figure, reference numeral 1 indicates a force-to-deflection converter made up of a substantially E-shaped spring similar to those described in connection with the foregoing examples. Reference numeral 61 designates a flapper of a thin sheet metal which is attached to the tip of the central leg 12 of the spring 1 and 62 a nozzle disposed in opposing relation to the flapper 61. Reference numeral 63 represents bellows, 631 a metal fixture of the bellows 63 on the side of its movable end for fixing the bellows 63 to the central leg 12 of the spring 1 by means of a screw 632 and 633 a metal fixture of the bellows 63 on the side of its fixed end, the bellows 63 being fixed to a mounting plate 64 by means of the metal fixture 633. Further, a pilot relay for amplifying the back pressure of the nozzle 62 and a feedback mechanism for feeding back the output of the pilot relay are provided.

This instrument is disposed by the mounting plate 64 in opposing relation to a bore 642 formed in a side wall 641 of a liquid bath 6. When a liquid pressure is applied to the bellows 63 in response to changes of the liquid level in the liquid bath 6, the bellows 63 expands to cause the flapper 61 61 to shift to the left in FIG. 15 through the central leg 12 of the spring 1. When the flapper 61 has shifted to the left, the gap between it and the nozzle 62 become narrower to raise the back pressure of the nozzle 62, by which the aforementioned pilot relay and feedback mechanism operate to provide an air pressure signal corresponding to the liquid level.

As has been described in the foregoing, the present invention provides an extremely excellent instrument for converting a force into an electric or air pressure signal.

It will be apparent that many modifications and variations may be effected without departing from the scope of the novel concepts of this invention.

What is claimed is:

1. A force-to-signal converter comprising a first means for receiving an external force, a second means for transmitting the external force applied to the external receiving means, a third means for converting the external force derived from the external force transmitting means into a deflection, a fourth means for converting the deflection of the third means into a signal, which is characterized in that the force-to-deflection converting means is a substantially E-shaped spring, the fourth means being a differential inductor which includes a short-circuiting ring, the short-circuiting ring being connected to the deflection point of the central leg of the E-shaped spring and disposed in a flux gap of the differential inductor to vary the inductance of the differential inductor with the deflection of the short-circuiting ring, thereby producing an electric signal corresponding to the external force.

2. A force-to-signal converter as claimed in claim 1 wherein reference faces are respectively formed in the E-shaped spring and the differential inductor for fixing the differential inductor to the E-shaped springs by utilizing the reference faces.

3. A force-to-signal converter as claimed in claim 1 wherein reference faces are respectively formed in the E-shaped spring and the differential inductor and a fixed portion having a reference face is provided to thereby fix the E-shaped spring and the differential inductor to the fixed portion on their reference faces so as to couple the differential inductor with the E-shaped spring by utilizing the reference faces.

4. A force-to-signal converter comprising a first means for receiving an external force, a second means for transmitting the external force applied to the external receiving means, a third means for converting the external force derived from the external force transmitting means into a deflection, a fourth means for converting the deflection of the third means into a signal, which is characterized in that the force-to-deflection converting means is a substantially E-shaped spring, the first means consisting of two thin plate like diaphragms and a circular block with a central aperture connected to a chember and having attached on the outsides thereof the two diaphragms, the second means being a movable rod disposed in the central aperture of the block, the movable rod being coupled at both ends thereof to the two diaphragms at their central portion, the E-shaped spring being disposed in the chember of the block, and the side legs of the E-shaped spring being fixed to the block at one ends thereof and the central leg of the E-shaped spring being fixed to the movable rod, and the fourth means being a differential inductor which includes a short circuiting ring disposed in the flux gap thereof, the short, circuiting ring being fixed to the deflection point of the central leg of the E-shaped spring to vary the inductance of the differential pressure applied to the two diaphragms to produce an electric signal corresponding to the differential pressure.

5. A force-to-signal converter as claimed in claim 4 wherein reference faces are respectively formed in the blocks, the E-shaped spring and the differential inductor for assembling them together as a unitary structure by utilizing the reference faces.

6. A force-to-signal converter comprising a first means for receiving an external force, a second means for transmitting the external force applied to the external receiving means, a third means for converting the external force derived from the external force transmitting means into a deflection, a fourth means for converting the deflection of the third means into a signal, which is characterized in that the force-to-deflection converting means is a substantially E-shaped spring, the first means being a bellows introducing therein a fluid and expanding or contracting in response to changes in the pressure of the fluid, the free ends of both side legs of the E-shaped spring being fixed to a fixed portion, the movable end of the bellows being fixed to the central leg of the E-shaped spring to deflect the free end of the central leg of the E-shaped spring with a force applied thereto from the bellows, and the our means being a differential inductor which includes a short-circuiting ring, the short-circuiting ring being attached to the central leg of the E-shaped spring at its deflection point to vary the inductance of the differential inductor with the deflection of the short-circuiting ring to thereby produce an electric signal corresponding to the external force.

7. faces force-to-signal converter as claimed in claim 6 wherein reference aces are respectively formed in the fixed portion, the E-shaped spring and the differential inductor for assembling them together as a unitary structure by utilizing the reference faces.

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