
Force Sensor

Description

The invention relates to an (individual) sensor for electrically measuring a force acting on the sensor which is distributed unevenly over a measurement surface of the sensor.

Personal scales are suitable for measuring a force acting on them, e.g. a force corresponding to the weight of a user, even if this force is distributed unevenly over the rigid standing surface. Such measurement becomes problematic when it is desired to measure a force applied by a user, e.g. in a shoe. Such measurement is necessary in the case of various medical indications, in particular when the person "monitored" is supposed to perform a specific exercise and has to access the force applied easily.

A capacitive measuring arrangement for determining forces or pressures in which a large number of individual sensors are distributed over a surface, e.g. an insole in a shoe, is known from DE 36 34 855 C1. The sensors in the case of the known arrangement consist of capacitors, i.e. of a large number of capacitor surfaces which are constructed in a matrix and are scanned individually as a matrix. A total force or a total pressure can be calculated from the sum of the individual forces or individual pressures. In this case, it hardly matters whether individual regions of the entire surface are under a greater or lesser load since the total surface is divided into smaller partial surfaces, so that partial forces can be measured and added up. If in the case of this arrangement the acting forces are distributed beyond the measurement surface, i.e. if the total sensor surface is too small, a correct measurement result cannot be derived.

When an elastic sensor (as mentioned above) is required, the measurement results in the case of full-surface sensor elements, e.g. capacitor films, are extremely inaccurate if the force is distributed unevenly.

It is an object of the invention to set forth a sensor of the type referred to first hereinbefore such that a correct total force measurement can be derived in a simple manner.

This object is achieved by a sensor according to Claim 1. Particular uses of the sensor are named in Claim 12.

In particular, this object is achieved by a sensor for electrically measuring a force (F) acting on the sensor within a specified measuring range, which force is distributed unevenly over a measurement surface (10) of the sensor, wherein an electrical force measurement signal is generated, comprising an areally formed spring device (20) which is arranged between the measurement surface (10) and a counter-surface (11), wherein a first measuring element (12) is arranged in or on the measurement surface (10) and a second measuring element (13) is arranged in or on the counter-surface, the elements substantially completely covering these surfaces in each case, wherein the measurement surface (10) and the counter-surface (11) plus the measuring elements (12, 13) are designed to be elastically deformable, wherein the measuring elements (12, 13), e.g. capacitor plates, are designed such that the measuring signal can be generated from a distance between the measuring elements (12, 13), wherein the spring device (20) has a large number of incompressible but elastically designed spring members (21 to 21_n) which are arranged spaced apart from each other by gaps (22) in such a way that each spring member (21 to 21_n) upon loading by the force (F) or a fraction of this force (F) can deform, into the gaps (22) and hence in a space-consuming manner, and wherein each spring member is designed such that its height between the measurement surface and the counter-surface upon loading of the sensor by the force (F) within the specified measuring range is linearly proportional to a partial force acting thereon.

Surprisingly, it has turned out that when the sensor is loaded by forces within a specified measuring range it is not necessary to operate with linearisation "over everything" as with rigid sensors, with which an even distribution of forces onto all the regions of the sensor takes place, regardless of how the effective forces are distributed. Depending on the specified measuring range, then the overall arrangement can be such that the spring members have a linear characteristic within measuring ranges of small area as well. As a result, it is possible to measure a force sum by means of the sensor, namely substantially independently of the distribution of the effective partial forces.

Furthermore, the measurement surface and the counter-surface plus the measuring elements are designed to be deformable, namely in particular elastically deformable.

Therefore it is not – as in the case for example of personal scales – rigid surfaces which are used as the measurement surface and counter-surface, but elastically resilient surfaces, so that for example an insole in a shoe can be designed as a sensor. Preferably in this case the measurement surface and/or the counter-surface are designed as a textile material or comprise a textile material, which may be in particular a knitted fabric or a woven fabric. Such materials are known per se. Particularly preferred is an embodiment in which the measuring elements comprise capacitor plates, with a capacitance between the capacitor plates being able to be measured to generate the force measurement signal. The technology necessary for this is already very well developed.

At this point it should be pointed out that the measuring elements may also be constructed as inductors or as ohmic resistors (or mixtures thereof), and that capacitor plates or capacitors as measuring elements are discussed as a preferred example of embodiment in the following description.

The measurement surface and/or the counter-surface are connected to the spring members by fastening means. These fastening means may be designed in diverse ways. What is important in this case is however that the measurement surface and the counter-surface be connected to the spring members such that the geometric overall arrangement remains substantially constant. In this case, the fastening means are preferably designed elastically such that the measurement surface and/or the counter-surface is/are elastically displaceable relative to the spring devices. This is necessary in particular when curving of the measurement surface or of the counter-surface occurs. Fastening means which are displaceable in such a manner may for example be elastic bonded joints.

The measurement surface and the counter-surface preferably have in addition to the first or second measuring element respectively, on their sides remote from the spring device, shielding elements for electrically shielding the measuring elements. As a result, even relatively small measuring signals can be detected with little disturbance.

The spring members may be constructed as geometric bodies in various ways. They may comprise bar-shaped, frusto-pyramidal or frusto-conical individual elements, "frusto-pyramidal" or "frusto-conical" also being taken to mean cuboids or cylinders with very slight angling. These individual elements are arranged at regular distances from each other. In particular silicone rubber is a suitable material here, with Shore hardnesses of 45 - 55, in particular 47 - 53, being preferred. Adaptation to the forces to be measured may of course be carried out here.

The spring members may – as described above – be connected together by a bonded joint, or alternatively by a carrier surface from which the individual spring members protrude either on one side or on both sides (with the carrier surface in the middle). In both cases, production of the sensor is particularly simple and precise when the carrier surface is designed in one piece with the spring members.

If the measuring elements comprise capacitor plates, preferably a capacitance measuring device is provided which is connected to the shielding elements and the capacitor plates and is designed such that capacitances between the capacitor plates and the shielding elements can be measured. Since – in a manner known per se – all the capacitor plates and also the shielding means are separated from one another by dielectrics, a measuring signal can be generated herefrom which corresponds substantially to the temperature-dependent material properties of the dielectrics, i.e. in particular the material-dependent and temperature-dependent dielectric constant. By means of this measuring signal, the force measurement signal can be corrected with respect to its temperature dependency in a correction device.

Many different combinations of form and material which permit the aforementioned linearisation are conceivable for the spring elements. In one embodiment, the spring members are assembled from spring members of different geometric construction in groups of spring members which in each case have different spring characteristics from each other, such that they compensate for each other and bring about linearisation of the overall spring characteristic of the group.

A sensor of the type shown here can advantageously be used for a large number of measurement tasks. In particular, these are those measurement tasks in which the surfaces between which the forces occur are curved or – and this is even more difficult with regard to the sensors to be selected – variable during the course of the measurement. In particular, they are in this case measurements of loads exerted by human limbs or effectors of a robot on a surrounding object, e.g. a shoe, a prosthesis, an orthosis, a handle, a steering wheel or a natural or artificial joint, and also tools or workpieces. These can also be taken to mean forces exerted by body parts on subjacent supporting structures, e.g. a car seat, a mattress, a lounge or a riding saddle.

Below, preferred embodiments of the invention will be illustrated in greater detail with reference to schematic drawings. Therein

- Fig. 1 is a partial cross-section through a first embodiment of the invention,
- Fig. 2 is a representation of the arrangement of Fig. 1 upon loading with an even force,
- Fig. 3 is a representation of the loading of an arrangement according to Fig. 1 with an uneven force,
- Fig. 4 is a top view of the arrangements of Fig. 1 - 3, omitting the measurement surface, with the dot-dash line A-A corresponding to the sections of Fig. 1 - 3,
- Fig. 5 is a more detailed partial section through a further embodiment of the invention,
- Fig. 6 is a section similar to that of Fig. 1, but through an arrangement according to Fig. 5,
- Fig. 7 is a section corresponding to that of Fig. 1 and 6 through a further embodiment of the invention,
- Fig. 8 is a top view of a further embodiment of the invention,
- Fig. 9 is a section along the line IX-IX of Fig. 8,
- Fig. 10 is a top view of a further embodiment of the invention,
- Fig. 11 is a section along the line XI-XI of Fig. 10,
- Fig. 12 is a top view of a further embodiment of the invention,
- Fig. 13 is a section along the line XIII-XIII of Fig. 12,
- Fig. 14 is a graph by way of example showing a linear range of the spring device,
- Fig. 15 is a schematic cross-sectional representation of groups of spring members, and

Fig. 16 is a graph corresponding to that of Fig. 15 explaining the spring characteristic of an arrangement according to Fig. 15.

In the following description, the same reference numerals are used for identical parts and for parts which have the same effect.

According to Fig. 1, the sensor comprises a measurement surface 10 and a counter-surface 11, with spring devices 20 being provided between the measurement surfaces 10 and 11. These spring devices 20 comprise spring members 21, 21₁, 21₂ and 21₃ which are connected together via a carrier surface 24. The spring members 21... are formed in one piece with the carrier surface 24 from silicone rubber.

If then a force F, as shown in Fig. 2, acts on the measurement surface 10, the spring members 21₁ to 21₃ deform, and therefore expand into gaps 22 which are provided between the bodies 21₁ to 21₃.

If the acting force F is distributed unevenly over the measurement surface 10, as is shown in Fig. 3, individual spring members 21₁ will deform more greatly than the adjacent spring members 21 and 21₂, with the measurement surface 10 being deformed at the same time. It is therefore important for the measurement surface 10 and generally also the counter-surface 11 to be elastically deformable.

The spring device 20 shown in Fig. 1 - 3 consists – as shown in Fig. 4 – of bars. This is a particularly simple "basic form".

In the arrangement shown in Fig. 5, a single spring member 21 which is designed substantially as a cuboid is provided. This spring member 21 is covered on both sides with measuring elements or electrodes 12 and 13. Between the electrodes 12 and 13 and outer shielding elements 15, 16 there is provided a dielectric 14. The overall arrangement, i.e. the measurement surfaces 10, 11, consisting of the measuring elements 12, 13, the shielding elements 15, 16 and the dielectric 14, is designed to be elastically deformable, so that deformation can take place as shown in Fig. 3.

Since the capacitance of the spring members 21 arranged between the measuring elements or electrodes 12, 13 is temperature-dependent with regard to its dielectric constant, it is advantageous if this temperature dependency can be compensated. To this end, in multiplex operation the measuring points A and B are connected in parallel and the capacitance between the electrodes 12, 13 (which are connected in parallel) and the

shielding elements 15, 16 is measured alternately to the capacitance between the measuring points A and B, i.e. between the electrodes 12 and 13. From these measurements, a correction signal can be ascertained which can make the capacitance between the measuring elements or electrodes 12, 13 respectively substantially independent of the temperature of the overall arrangement. The electrical circuit necessary for this is not shown separately, since it is in principle familiar to the person skilled in the art who is active in this field.

Fig. 6 once again shows an arrangement corresponding to that of Fig. 5. In this case, the spring members 21 to 21₃ are connected directly to the measurement surface 10 or the counter-surface 11, which can be done e.g. by gluing. If the adhesive layer is elastic, this is advantageous when curving or sagging of the overall arrangement occurs.

In the arrangement of Fig. 7, the spring members 21 to 21₃ are arranged on either side of a carrier surface 24, so that a very symmetrical arrangement is produced.

In the arrangement of Fig. 8, the spring members 21_m to 21_n are designed to be frusto-pyramidal, as is shown in Fig. 9. In this case, the arrangement is such that it is possible for the spring members 21_m to 21_n to yield sideways.

The arrangement of Fig. 10 and 11 differs from that of Fig. 8 by a larger grid pattern of spring members 21_m to 21_n.

The arrangement of Fig. 12 and 13 corresponds to that of Fig. 10, but with the angle of the truncated pyramids to the carrier surface 24 being substantially 90°.

The forming of the spring members 21 to 21_n mentioned first hereinbefore results in a spring characteristic in accordance with Fig. 14. Within a measuring range between a minimum force $F_{\min}$ and a maximum force $F_{\max}$ the change in form, i.e. the change in height d (see Fig. 15) of the spring members 21 to 21_n between a value $1/d_{\min}$ and a value $1/d_{\max}$, runs substantially linearly. Depending on the requirement, i.e. depending on the measurement task, the geometric form and size and also the material are determined such that measurements in the linear range according to Fig. 14 are made possible.

One possible way of linearising spring members consists in dividing them into groups 21', 21"; 21₁', 21₁", 21₂', 21₂", the various members 21' and 21"... being of geometrically different forms and having different spring characteristics (i.e. ratio d/F), as shown in Fig. 16. The spring member 21' shown in Fig. 15 is based on bulging of the spring member

walls, so that with increasing deformation the force necessary for this decreases, whereas in the case of the "solid" spring member 21" the force increases. When added together, the two non-linear curves thereby compensate for each other. It is of course possible to have a large number of different combinations of spring members cooperate here.

List of reference numerals

10	measurement surface
11	counter-surface
12	first measuring element/electrode
13	second measuring element/electrode
14	dielectric
15	first shielding element
16	second shielding element
20	spring device
21 to 21 _n	spring members
22	gap
24	carrier surface

Claims

1. A sensor for electrically measuring a force (F) acting on the sensor within a specified measuring range, which force is distributed unevenly over a measurement surface (10) of the sensor, wherein an electrical force measurement signal is generated, comprising

an areally formed spring device (20) which is arranged between the measurement surface (10) and a counter-surface (11),
wherein a first measuring element (12) is arranged in or on the measurement surface (10) and a second measuring element (13) is arranged in or on the counter-surface, the elements substantially completely covering these surfaces in each case,
wherein the measurement surface (10) and the counter-surface (11) plus the measuring elements (12, 13) are designed to be elastically deformable,
wherein the measuring elements (12, 13) are designed such that the measuring signal can be generated from a distance between the measuring elements (12, 13),
wherein the spring device (20) has a large number of incompressible but elastically designed spring members (21 to 21_n) which are arranged spaced apart from each other by gaps (22) in such a way that each spring member (21 to 21_n) upon loading by the force (F) or a fraction of this force (F) can deform, into the gaps (22) and hence in a space-consuming manner, and
wherein each spring member is designed such that its height between the measurement surface and the counter-surface upon loading of the sensor by the force (F) within the specified measuring range is linearly proportional to a partial force acting thereon.
2. A sensor according to one of the preceding claims,
characterised in that
the measurement surface (10) and/or the counter-surface (11) comprise textile material, in particular a knitted fabric or a woven fabric.
3. A sensor according to one of the preceding claims,
characterised in that

the measuring elements (12, 13) comprise capacitor plates, with a capacitance between the capacitor plates being able to be measured to generate the force measurement signal.

4. A sensor according to one of the preceding claims,
characterised in that
the measurement surface (10) and/or the counter-surface (11) are connected to the spring members (21 to 21_n) by fastening means (24).
5. A sensor according to Claim 4,
characterised in that
the fastening means (24) are designed elastically such that the measurement surface (10) and/or the counter-surface (11) is/are displaceable relative to the spring device (20).
6. A sensor according to one of the preceding claims,
characterised in that
the measurement surface (10) and the counter-surface (11) comprise in addition to the first or second measuring element (12, 13) respectively, on their side remote from the spring device (20), shielding elements (15, 16) for electrically shielding the measuring elements (12, 13).
7. A sensor according to one of the preceding claims,
characterised in that
the spring members (21 to 21_n) are arranged at regular distances from each other and are preferably designed as bar-shaped, frusto-pyramidal or frusto-conical individual elements, the spring members (21 to 21_n) preferably being manufactured from silicone rubber, in particular with a Shore hardness of 45 - 55, in particular 47 - 53.
8. A sensor according to one of the preceding claims,
characterised in that
the spring members (21 to 21_n) are connected together via at least one carrier surface (24).
9. A sensor according to Claim 8,
characterised in that

the carrier surface (24) is designed in one piece with the spring members (21 to 21_n).

10. A sensor according to Claim 6,
characterised in that
the measuring elements (12, 13) comprise capacitor plates, and in that a capacitance measuring device is provided which is connected to the shielding elements (15, 16) and the capacitor plates (12, 13) and is designed such that capacitances between the capacitor plates (12, 13) and the shielding elements (15, 16) can be measured in order to obtain a temperature signal and the force signal can be corrected corresponding to the temperature signal by means of a correction device.
11. A sensor according to one of the preceding claims, characterised in that the spring members (21 to 21_n) comprise in each case groups of spring members (21', 21'' to 21'_n, 21''_n) which in each case have a spring characteristic which are inverse to one another, such that they compensate for each other and bring about linearisation of a group spring characteristic.
12. Use of a sensor according to one of the preceding claims for measuring loads exerted by human limbs or effectors of a robot on a surrounding object.
13. Use of a sensor according to Claim 12,
characterised in that
the surrounding object is a shoe, a prosthesis, an orthosis, a handle, a steering wheel, a natural or an artificial joint, a tool or a workpiece.