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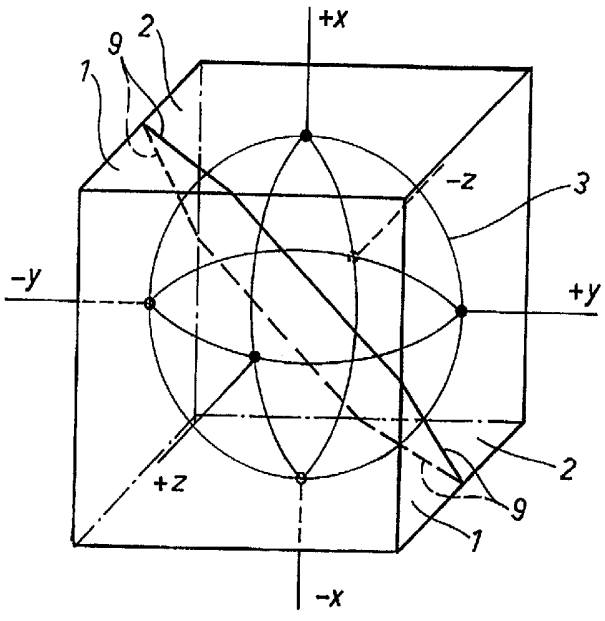
(54) Title: SENSOR DEVICE FOR THE 3-DIMENSIONAL MEASUREMENT OF AN ATTITUDE OR ACCELERATION

(57) Abstract

The invention relates to a sensor device for measuring attitude, acceleration or gravitational field and its gradient components. The device includes a spherical cavity (3) which contains a sensor substance in the form of a fluid or some other inertial material having fluidic properties. The cavity (3) is provided with measuring sensors or measuring electrodes (-x, +x; -y, +y; -z, +z) for three different coordinate axes x, y, z, all of said sensors responding to said common inertial mass which fills the cavity (3). Such assembled single compact measuring device can be used for determining any of the said quantities 3-dimensionally.



Sensor device for the 3-dimensional measurement of an attitude or acceleration.

The present invention relates to a sensor device for measuring an attitude, acceleration or gravitational field and its gradient components, said device including a spherical cavity which contains a sensor substance in the form of a fluid or some other inertial material having fluidic properties.

An accelerometer provided with a spherical cavity is prior known e.g. from Patent publication US 3461730. This prior known device produces an absolute acceleration value regardless of direction. Unlike this, a device of the invention can be used for sensoring an acceleration as a vector quantity. Neither does the prior known device include any indications for identifying the attitude of the device, while one of the fundamental features of the present invention is the identification of an attitude of the device.

As for the prior art, reference can also be made to publications US 3992951 and EP 0566130. The latter relates to a sensor for rotational motion, describing the principles of sensor elements or transducers which can be applied also in the present invention. In other words, the sensors may comprise piezoelectric transducers, capacitive membrane sensors and elongation strip sensors. Other types of sensors or transducers can also be used, as described in more detail hereinafter.

An object of the invention is to provide a sensor device, capable of determining the attitude of the device or the rate and direction of its acceleration 3-dimensionally. In other words, the sensor device must have an equal directionality in all directions to make it capable of

sensoring an acceleration vector, in addition to which the device also serves as an attitude identifier.

This object is achieved by means of the invention on the basis of the characterizing features set forth in the annexed claims.

Some of the application areas for a sensor device of the invention are e.g. as follows:

- in industrial manufacturing and robotics as attitude identifier or a triaxial sensor for linear motion (acceleration)
- in navigation systems (inertial navigation) in land vehicles, water- and aircraft, in various self-controlled or self-navigated mobile devices
- in so-called black boxes of vehicles (when the kinetic history of a vehicle is to be recorded)
- in geophysics, geotechnique and in other areas of construction engineering e.g. as a triaxial vibration transducer, as an attitude sensor in drill holes, as a motion/attitude sensor for equipment towed by survey vessels, and as a sensor for gravitational field measuring equipment.

The invention will now be described in more detail with reference made to the accompanying drawings, in which

fig. 1 shows a spherical cavity in a measuring sensor with its 3-D coordinate axes;

fig. 2 shows the same cavity, having its inertial fluid subjected to the action of a vector force $\bar{F}$;

fig. 3 shows one structural design for a sensor unit in a sensor device of the invention according to one exemplary embodiment; and

fig. 4 is a block diagram, showing an example of a measuring circuit design for a sensor device.

First explained is the theoretical background of the invention with reference to figs. 1 and 2. In the arrangement of fig. 1, a spherical container 3 contains a fluid at a pressure Po. The container 3 is provided with imaginary rectangular coordinates x, y, z, whose positive axial directions intersect the spherical surface at points P_1, P_3 and P_5 and negative axial directions at points P_2, P_4 and P_6, respectively.

At least the points P are provided with sensors (measuring sensors or electrodes), which sample some material property of the sensor fluid as a function of the fluid pressure.

If a body, which contains the fluid container 3, travels at an acceleration $\bar{F}$, the fluid within the container, as a result of inertia, develops a pressure whose magnitude at its maximum is

$$p = 2\gamma|\bar{F}|r \qquad (1)$$

wherein γ = fluid density and r = container radius.

This pressure is 0 at the point where the direction of an acceleration vector extending through the centre of the spherical surface intersects said spherical surface and the maximum pressure value according to formula (1) is found at the intersection of the opposite vector direction and the spherical surface.

If T is a normal plane for the vector $\bar{F}$, extending through a point P_n (n = 1...6), it can be concluded on the basis of fig. 2 that:

- the distance between the plane T and the centre of the spherical surface is

$$\bar{F}^{\circ} \cdot (\overrightarrow{OP_n})$$

$= \bar{F}^\circ \cdot r\bar{q}_n^\circ$

$= r\,(\bar{F}^\circ \cdot \bar{q}_n^\circ) = r\cos\theta_n$

- the distance of the plane T from a point, at which the inertia-induced fluid pressure = 0, is $r(1 - \cos\theta_n)$
- at the point P_n prevails a pressure $p_n = \gamma r\,(1 - \cos\theta_n)\,F$
- pressure $p_{n+1} = \gamma r\,(1 + \cos\theta_n)\,F$

since $\cos(\theta + \pi) = -\cos\theta$

In the above formulae and in fig. 2

$OP_n = r\bar{q}_n^\circ$

r = radius

$\bar{q}_n^\circ$ = unit vector

$\bar{F}^\circ$ = unit vector in the direction of $\bar{F}$

θ_n = intervectorial angle

If, according to the starting premise, the fluid is further thought to have a pressure p_o, the points P_n and $P_n + 1$ can be measured to have pressures $(p_n + p_o)$ and $(p_{n+1} + p_o)$.

When $\Delta p_n = (p_n + p_o) - (p_{n+1} + p_o) = p_n - p_{n+1} = 2\gamma r F\cos\theta_n$

$$\begin{aligned} \Delta p_1 &= p_1 - p_2 = 2\gamma F r\cos\theta_1 \\ \Delta p_2 &= p_3 - p_4 = 2\gamma F r\cos\theta_2 \\ \Delta p_3 &= p_5 - p_6 = 2\gamma F r\cos\theta_3 \end{aligned} \qquad (2)$$

On the basis of this

$(\Delta p_1)^2 + (\Delta p_2)^2 + (\Delta p_3)^2\ (2\gamma F r)^2\ (\cos^2\theta_1 + \cos^2\theta_2 + \cos^2\theta_3)$

which has a consequence that

$$F = \frac{1}{2\gamma r}\sqrt{(\Delta p_1)^2 + \Delta p_2)^2 + (\Delta p_3)^2}$$

$$\begin{aligned} \cos\theta_1 &= \Delta p_1\,[(\Delta p_1)^2 + (\Delta p_2)^2 + (\Delta p_3)^2]^{-\frac{1}{2}} \\ \cos\theta_2 &= \Delta p_2\,[(\Delta p_1)^2 + (\Delta p_2)^2 + (\Delta p_3)^2]^{-\frac{1}{2}} \\ \cos\theta_3 &= \Delta p_3\,[(\Delta p_1)^2 + (\Delta p_2)^2 + (\Delta p_3)^2]^{-\frac{1}{2}} \end{aligned} \qquad (3)$$

the rate and direction of the acceleration vector $\bar{F}$ relative to the system axes is thus determined. In the sim-

plest case, the relationship between a signal and pressure to be measured at points P_n is linear. Signal = k x pressure.

$S = k \times p$, whereby $P_n = \frac{1}{k} S_n$

and

$$F = \frac{1}{2\gamma r k} \sqrt{(\Delta S_1)^2 + \Delta S_2)^2 + (\Delta S_3)^2}$$

$$\begin{aligned} \cos\theta_1 &= \Delta S_1 \, [(\Delta S_1)^2 + (\Delta S_2)^2 + (\Delta S_3)^2]^{-\frac{1}{2}} \\ \cos\theta_2 &= \Delta S_2 \, [(\Delta S_1)^2 + (\Delta S_2)^2 + (\Delta S_3)^2]^{-\frac{1}{2}} \\ \cos\theta_3 &= \Delta S_3 \, [(\Delta S_1)^2 + (\Delta S_2)^2 + (\Delta S_3)^2]^{-\frac{1}{2}} \end{aligned} \qquad (4)$$

In cases other than the simple relationships shown in the above formulae, the pressure is determined in each case according to individual measuring points and then by applying the formulae according to equation groups (2) and (3).

In order to determine the pressure from measured signals, it is possible to use a computer or other microprocessor-controlled calculating circuits.

Fig. 4 depicts one example of a measuring circuit design in the case of a passive sensor. A piezo sensor 4 or other pressure responsive sensor is placed at a measuring point P_n. A preamplifier 5 amplifies a sensor signal, which is fed by way of a signal adapter 6 to an A/D converter 7. The digital signals received from various sensors are fed to a computer 8, which performs the necessary calculations in accordance with the above formulae.

Fig. 3 illustrates a sensor unit which comprises a cubic-shaped body, which is assembled from separate pieces 1, 2 on the opposite sides of a division plane 9 with the halves of a spherical cavity 3 machined and the sensors

fitted therein prior to joining the cubic halves together.

The sensor material filling the cavity 3 comprises a fluid, liquid or gas or some other substance with fluidic properties, such as gels or colloids. If the sensor fluid to be used is electrically or optically neutral relative to pressure, the pressure is measured directly by means of a sensor (passive or active) integrated in the system. An essential feature in the invention is that the sensor fluid is common to all sensors performing 3-dimensional measuring. The sensors may respond to changes in the pressure of a sensor fluid, e.g. with one of the following results:

- a change in the charge or potential of a piezocrystal or plastics included in a sensor element
- a capacitance change in a capacitive sensor element caused by the penetration of a sensor substance into the element
- a change in the dimensions of a cavity resonator or resonance cavity of a wave tube.

Sensor substances, which have electrical or optical responses as a result of pressure existing in the substance, may respond to pressure variations caused by acceleration, e.g. with one of the following results:

- dielectric polarization (changes in an intra-substance electric field)
- a change in electric conductivity (piezoresistivity)
- a change in optical properties
- piezoelectricity.

When using this type of sensor substances, the sensor substance within the cavity may be an integral part of measuring sensors. For example, the mere electrodes on the surface of a cavity are adapted to measure changes occurring in the sensor substance.

A sensor device of the invention is characterized in that the construction measuring 3-dimensionally its attitude or acceleration has been created as a compact unit having a high degree of integration. At the moment, such an achievement requires the arrangement of three separate sensor devices whose assemblage involves both mechanical problems and problems relating to the processing of results. These problems have been resolved by means of a sensor device of the invention.

The sensor device is capable of measuring the attitude of its base which is at rest or in constant motion. In case the sensor device is in accelerating motion and it is desirable to measure acceleration of the motion as a vector quantity, the gravitational acceleration and the attitude must be known or brought into the system from an external source. If it is desirable to measure an attitude while the sensor device is in accelerating motion, the acceleration of the motion must be known or brought into the system from external sources.

As is known, the pressure difference between two points in a fluid due to gravitational acceleration, is related to the gravitational potential difference between the same points.

Thus second order partial differentials of pressure are related to the tensor components of the gravitational field gradient.

This implies that the present invention can be used also for measuring all of the gradient components of the gravitational field, in case the pressure sensoring locations are added as necessary.

The Swedish Patent Office
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Claims

1. A sensor device for measuring attitude, acceleration or gravitational field and its gradient components, said device including a spherical cavity (3), and measuring sensors or measuring electrodes referenced for their location to three mutually independent coordinate axis x, y, z in space, all of said sensors responding to common inert mass which fills the cavity (3), c h a r a c t e r i z e d in that the common inert mass is a sensor substance in the form of a fluid or some other inertial material having fluidic properties, the sensor substance completely filling the cavity (3) and responding to pressure fluctuations caused by acceleration such that there occur changes in the distribution of a physical field quantity or material properties of the sensor substance, the measuring sensors or electrodes being adapted to measure said changes.

2. A sensor device according to claim 1, c h a r a c t e r i z e d in that through the centre of the cavity (3) extend three coordinate axes x, y, z, which are perpendicular to each other and provided with measuring sensors or electrodes (-x, +x; -y, +y; -z, +z) at least on the locations on the inner surface of the cavity (3).

3. A sensor device as set forth in claim 1 or 2, c h a r a c t e r i z e d in that the measuring sensors respond to pressure changes in the sensor substance.

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AMENDED SHEET

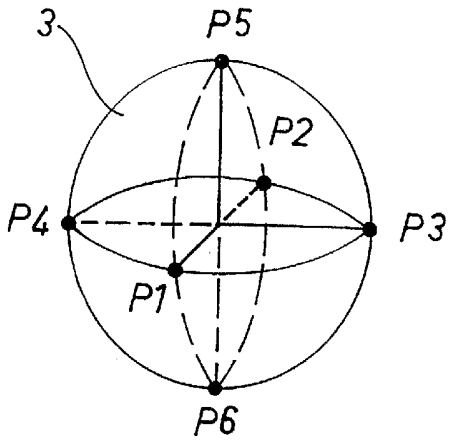

Fig. 1

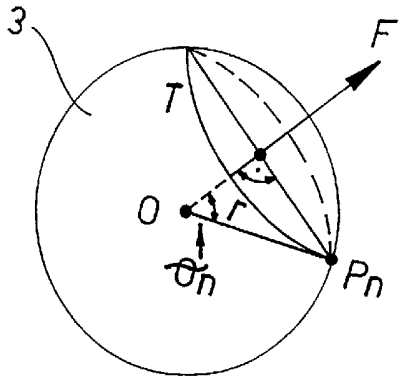

Fig. 2

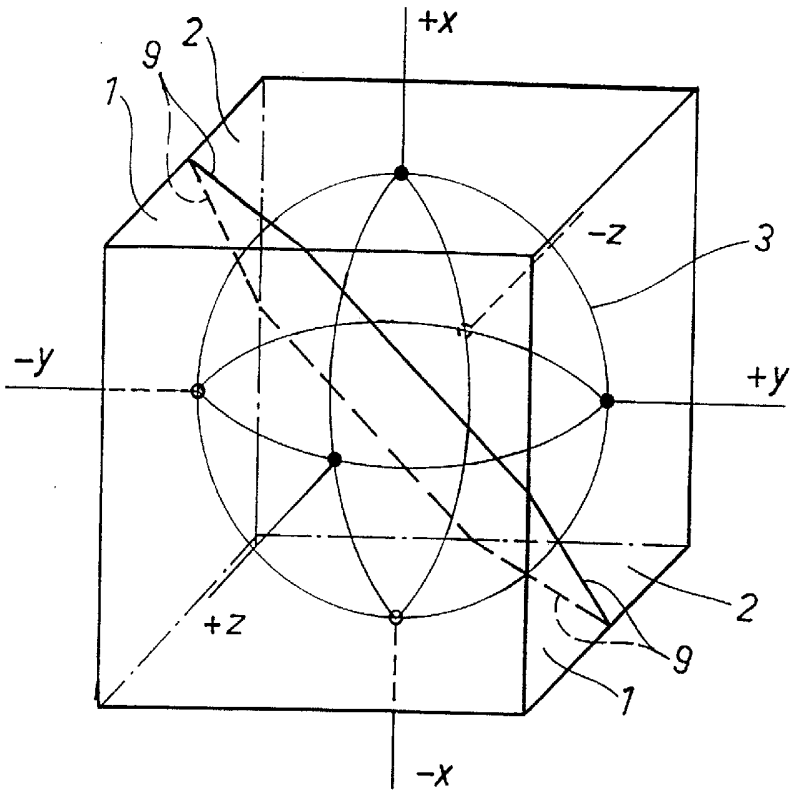

Fig. 3

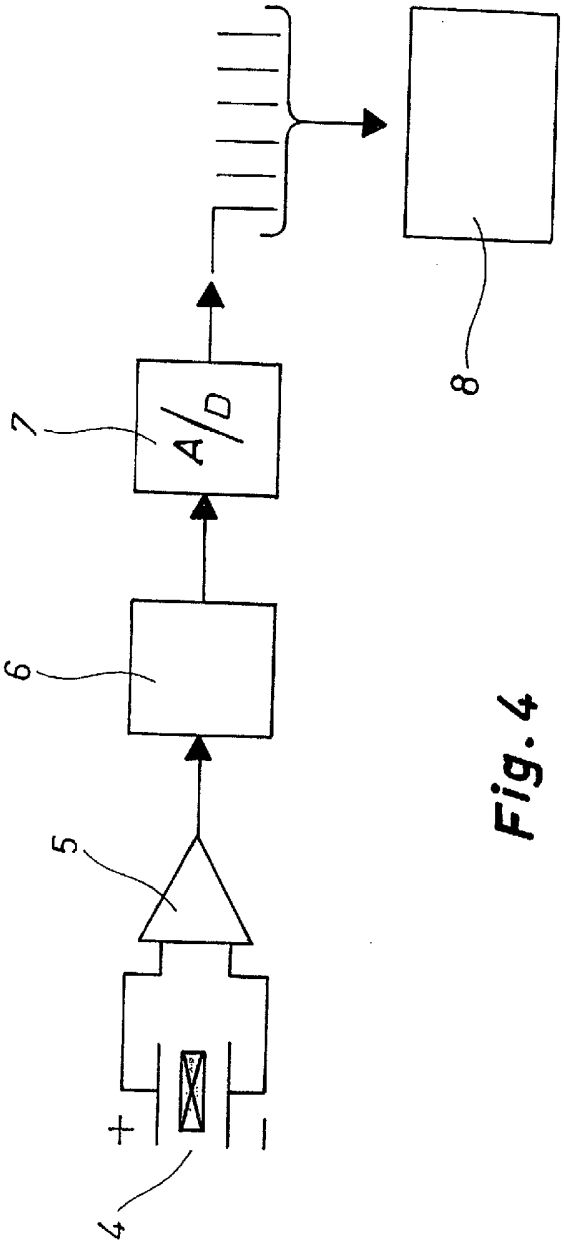

Fig. 4