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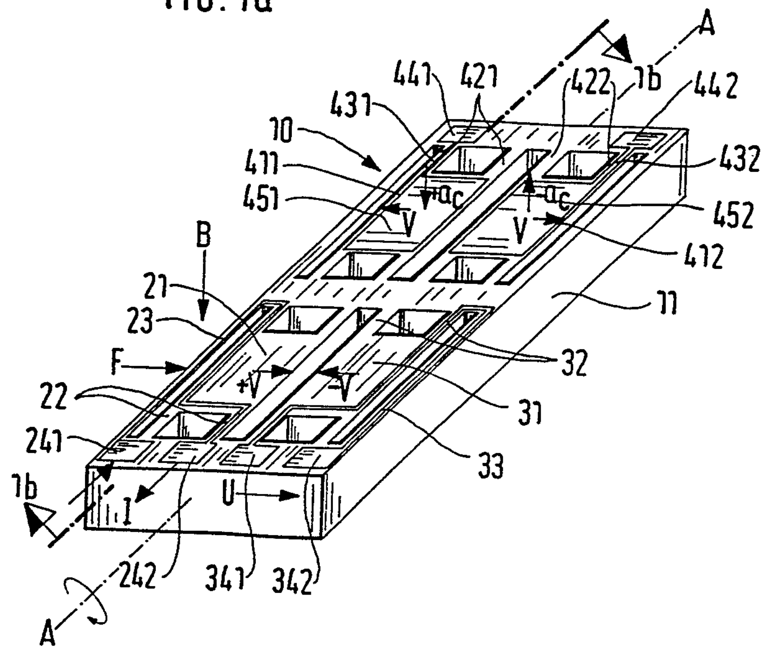
GB 2186085 A

(58) Field of search
UK CL (Edition K) **G1G GED GPGA**
INT CL[5] **G01C 19/56, G01P 9/04**

(54) **Rate-of-rotation sensor**

(57) A rate-of-rotation sensor having a sensor element is proposed which exhibits a fixed frame 11 and at least one resonator 21, 31, 411, 412 which is connected to the fixed frame via one or more webs 22, 32, 421, 422 and is capable of vibrating in two mutually perpendicular directions. The rate-of-rotation sensor exhibits means for exciting the at least one resonator in a first direction of vibration which is located in the plane of the frame. Furthermore, means exist for detecting deflections of the at least one resonator in the second direction of vibration. The rate-of-rotation sensor exhibits at least one cover (131, 132, fig 1b not shown) for the sensor element in the second direction of vibration. The sensor element has a layered structure, at least one layer being formed by a ceramic substrate. From this ceramic substrate, parts of the frame, parts of the at least one resonator and the webs are structured. The circuit elements for exciting the at least one resonator and for detecting measurement signals are applied to the ceramic substrate in thick-film technology, by means of thick-film pastes applied in a screen printing process and subsequently burnt.

FIG. 1a



GB 2 251 688 A

FIG. 1a

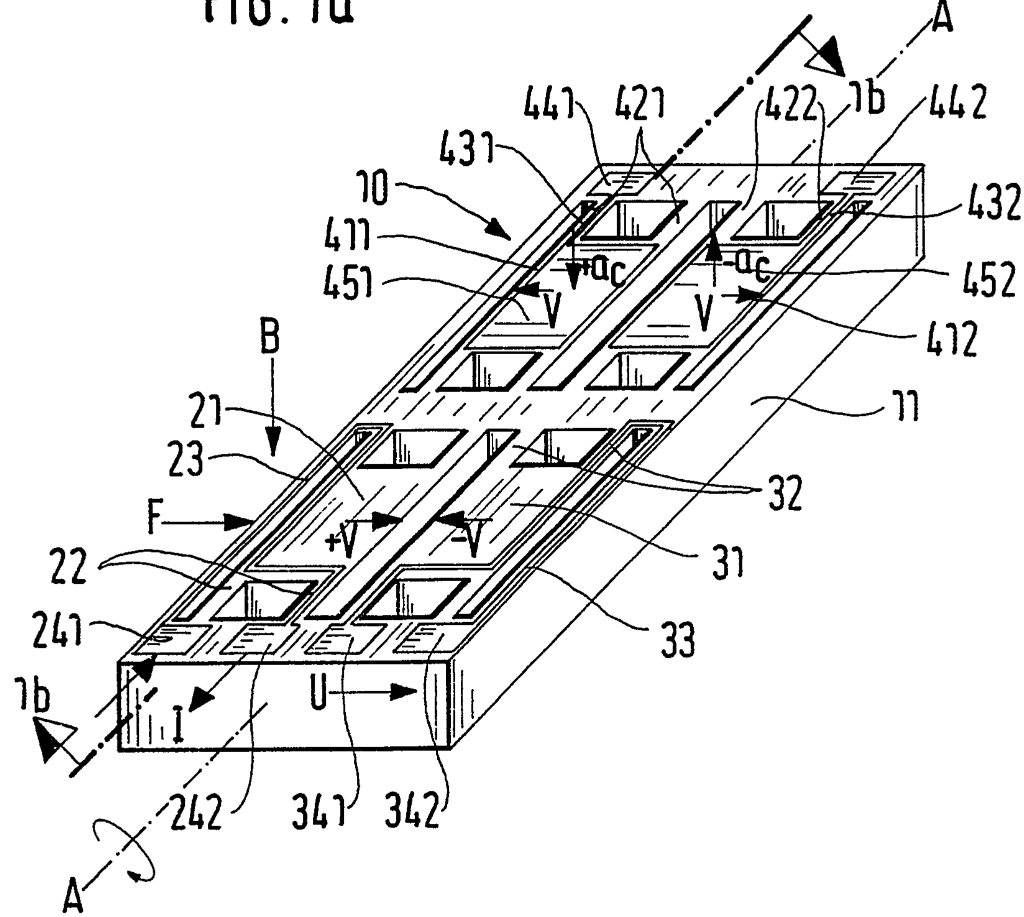

A
1b
441
421
422
1b
442
431
10
432
411
$+a_c$
$-a_c$
452
451
V
V
412
B
11
21
23
32
F
+V
-V
31
22
241
33
1b
I
U
242
341
342
A

FIG.1b

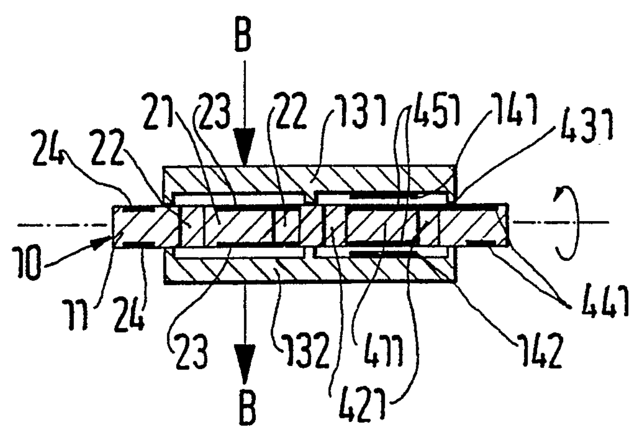

B
21
23
22
131
451
141
431
24
22
10
11
24
23
132
411
142
441
421
B

FIG.2a

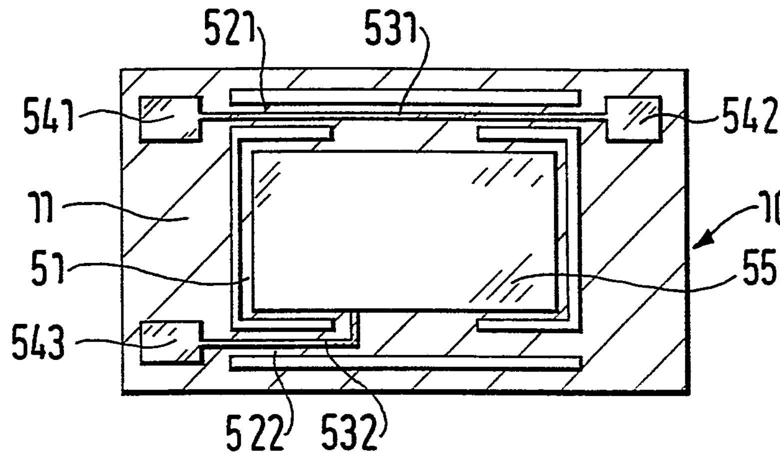


FIG.2b

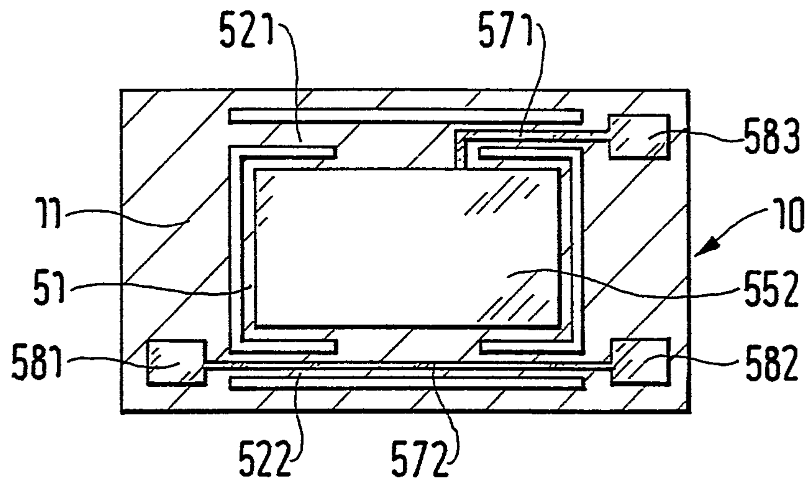


FIG.3a

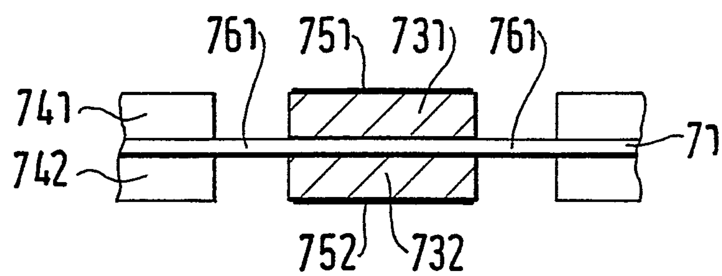
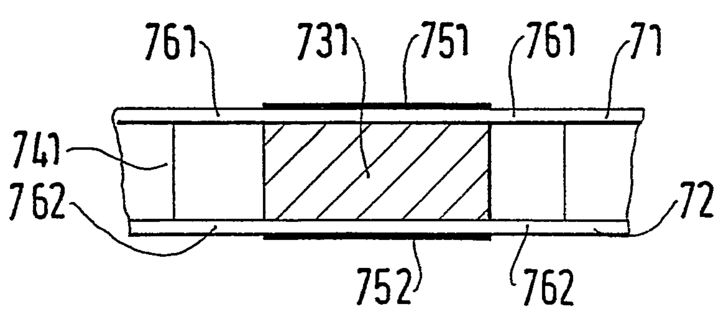


FIG.3b



Rate-of-rotation sensor

Prior art

The invention is based on a rate-of-rotation sensor of the generic type of the main claim.

It is already known, for example for measuring the speed of rotation of a vehicle essentially about the vertical axis, for controlling the dynamic driving characteristics or also for navigation purposes, to measure low rates of rotation from one revolution in the range of several degrees per second by means of sensors in which a tuning fork structure, which is oriented parallel to the axis of rotation, is excited to produce vibrations in one plane. During a rotation about the axis of rotation, the Coriolis force acts on the vibrating tuning fork tines perpendicularly to the axis of rotation and perpendicularly to the direction of excitation. The rate of rotation can be detected via the deflection of the tines perpendicular to the direction of excitation, caused by the Coriolis force, and analysed.

In US Patent Specification 4 836 023, a rate-of-rotation sensor with resonators and with means for suspending the resonators from a frame is described which operates in accordance with the principle explained initially. The resonators are constructed to be cube-shaped and mounted on the frame by means of four suspensions. The resonators, the suspensions and the frame are structured from a single block of material of uniform elasticity. Both the excitation of the resonators to vibration and the signal pick-up are effected piezo-electrically. The piezoelectric elements arranged on the resonators are connected via conductive thin-film layers to external circuits. In addition, the sensor exhibits an upper and a lower cover.

In German Patent Specification 34 17 858, it is proposed to fabricate the sensor structure from piezoelectric material, for example from quartz or synthetic crystals. In addition, sensor systems having several tuning fork structures are described in which essentially tuning fork structures are mounted in pairs at right angles or parallel to a shaft and fastened thereto, the said shaft being arranged between two fixed frame elements. In addition, it is proposed to detect the measurement signal capacitively.

In German Offenlegungsschrift 38 14 950, various methods of building up an accelerometer in thick-film technology are described.

Advantages of the invention

The sensor according to the invention, having the characterising features of the main claim, is particularly advantageous since it can be fabricated with a small constructional volume and inexpensively. It is of particular advantage that the essential elements of the sensor are fabricated in a uniform technology, namely in thick-film technology. Fabrication in thick-film technology is cost-effective even with relatively short production runs. A further advantage of fabrication in thick-film technology is that the methods of this technology are tried and tested and can be easily managed. Thus, the mechanical structure of the rate-of-rotation sensor can be created either by laser cutting from burnt ceramic or by shaping the structure from unburnt ceramic and subsequent burning. The application of conductor tracks, strain gauge resistors and other circuit elements and their contacts can also be implemented in thick-film technology, for example by the structured application of thick-film paste in a screen printing process and subsequent burning.

Advantageous further developments of the sensor specified in the main claim are possible by means of the measures listed in the subclaims. The excitation of the at least one resonator in the first direction of vibration, the direction of excitation, can advantageously occur piezoelectrically. For this purpose, driveable piezoelectric elements are also applied in thick-film technology to the webs and/or the resonator without requiring an additional production step. A further advantageous possibility for the piezoelectric drive consists in fabricating the sensor element or parts of the sensor element from piezoelectric ceramic having a polarisation suitable for exciting the resonator in the first direction of vibration.

However, the excitation of the resonator in the first direction of vibration can also be advantageously effected electrodynamically. A particularly simple and advantageous measure for implementing an electrodynamic drive is represented by a conductor track applied to the frame, the webs and/or the resonator, which track can be connected via connecting pads in such a manner that when an excitation voltage is applied, a current I flows essentially perpendicularly to the first direction of vibration. Furthermore, means exist for applying a magnetic field which is oriented parallel to the second direction of vibration. Due to the current I and the magnetic field B and their orientation with respect to one another and to the direction of excitation, a Lorentz force acts on the resonator in the direction of excitation. The possibility of controlling the excitation frequency and excitation amplitude by means of a further conductor track which is essentially oriented perpendicularly to the first direction of vibration and can be connected via further connecting pads, so that when the resonator moves in the first direction of vibration and when the magnetic field B is present, a control voltage U can be picked up, is particularly advantageous with respect to an electrodynamic drive. In addition, means are also required for changing the current I as a function of the control voltage U.

Evaluating the Coriolis acceleration as a measurement signal is advantageously done by means of a differential arrangement. One possibility consists in detecting the deflection of the at least one resonator in the second direction of vibration both at its top and at its underside and in forming the difference between these measurement signals. As a result, the measurement signal is advantageously amplified and linearised. Implementing the rate-of-rotation sensor in thick-film technology provides a possibility for a particularly compact construction of the rate-of-rotation sensor in which the ceramic substrate forming the sensor element is printed on both sides with electrodes and conductor tracks so that a functional sensor with differential arrangement can already be achieved by means of a single resonator. The Coriolis acceleration is then picked up at the same resonator as the controlled excitation in the first direction of vibration. To suppress interference, it is advantageous to select as sensor element a multiple arrangement of resonators which are mechanically coupled to one another. For the detection of the measurement signal, oppositely directed deflections are detected on two different resonators and then the difference between the respective measurement signals is formed. As a result, interference due to linear acceleration of the resonators in addition to the Coriolis acceleration is not included in the measurement result.

The measurement signals can be advantageously produced piezoresistively by means of thick-film resistors or strain gauges applied to the surfaces of the webs and/or of the at least one resonator in areas of maximum strain. Another advantageous possibility consists in selecting as ceramic substrate a piezoelectric ceramic having a polarisation which is suitable for detecting the deflections of the at least one resonator in the second direction of vibration. It is of particular advantage to detect the measurement signals capacitively. For this purpose, electrodes are applied to the surfaces of the resonators, which form the first electrode side of a measuring capacitor. On the covers of the sensor element, further electrodes are applied which form the second side of the measuring capacitor. This arrangement can also be implemented simply and advantageously in thick-film technology. To increase the sensitivity of the rate-of-rotation sensor, it is advantageous to increase the mass of the resonators. A simple possibility for this consists in overglazing further ceramic layers or also glass layers in the area of the resonators. The mass of the resonator can also be advantageously increased by means of a multilayer structure of the sensor element by constructing the resonator in several layers and suspending it from thin, symmetrically arranged webs. In a structure consisting of three ceramic layers joined via glass thick films, for example, the webs are only formed in the two outer ceramic layers in contrast to the resonator which is formed in all three layers.

Drawing

Illustrative embodiments of the invention are explained in greater detail in the description which follows and are shown in the drawing, in which:

Figure 1a shows a perspective view of a sensor element having four resonators,

Figure 1b shows a section through a sensor having one sensor element according to Figure 1a,

Figures 2a and b show the top and underside of a sensor element,

Figure 3a shows a detail of a section through a sensor element, and

Figure 3b shows a detail of a section through a further sensor element.

Description of the illustrative embodiments

Figure 1a shows a sensor element 10 which is structured from a ceramic base. It exhibits a multiple arrangement of four resonators 21, 31, 411 and 412 which are suspended from a frame 11 via webs 22, 32, 421 and 422 in such a manner that they form a dual tuning fork structure and are mechanically coupled. The two resonators 21 and 31 form a simple tuning fork structure and are used for driving the two resonators 411 and 412. For this purpose, a conductor track is applied to the webs 22, the frame 11 and the resonator 21, to which conductor track a preferably oscillating drive voltage can be applied via connecting pads 241 and 242 so that a current I flows. Arrow B indicates that a magnetic field B acts perpendicularly to the base surface. Due to the current I flowing in the conductor track 23, the Lorentz force F acts on the resonator 21, as shown by the arrow F. As a result, the resonator 21 can be excited to produce vibrations which are transferred to the resonator 31, the resonators 21 and 31 vibrating in opposite directions. On the webs 32, the frame 11 and the resonator 31, a further conductor track 33 is applied at which a voltage U induced due to the movement of the resonator 31 in the magnetic field B can be picked up via connecting pads 341 and 342. This voltage U is directly proportional to the speed V of the resonator 31 or of the resonator 21 which, of course, is mechanically coupled to the resonator 31. Picking up the voltage U is used for controlling and stabilising the excitation vibrations by varying the current intensity I. The resonators 411 and 412 are mechanically coupled to the resonators 21 and 31. To the surfaces of the former are applied, in each case electrodes 451 and 452 which can be connected via feed lines 431 and 432 and connecting pads 441 and 442. During a rotary movement about an axis of rotation A which is in the plane of the base and oriented perpendicularly to the direction of excitation, an oppositely directed Coriolis acceleration acts on the resonators 411 and 412, excited into vibrations, perpendicularly to the plane of the base in accordance with the oppositely directed speeds of the resonators 411 and 412 in the direction of excitation. The Coriolis acceleration ac in this example is detected as a change in capacity between the electrodes 451 and 452 and counterelectrodes applied to the cover, not shown in Figure 1a, since the Coriolis acceleration ac leads to a deflection of the resonators 411 and 412 in the direction of the Coriolis acceleration ac.

Figure 1b shows a section through a sensor having a top cover 131 and a bottom cover 132 and a sensor element 10 according to Figure 1a. On the covers 131 and 132, counter electrodes 141 and 142 are in each case applied in the area of the resonator 411. The sensor element 10 is printed on both sides with conductor tracks 23 for vibration excitation and with electrodes 451 for detection of the measurement signal, and with connecting pads 441 and conductor tracks 431. The webs 22 and 421 are formed in the entire thickness of the sensor element 10.

The sensor structure shown in Figures 1a and 1b provides the possibility for two different types of differential analysis of the measurement signal. At a resonator printed on both sides with electrodes, opposite which counter electrodes are arranged on an upper and a lower cover, two oppositely directed measurement signals, from which the distance can be formed as a result of which the measurement signal is amplified and linearised, can be capacitively detected during a deflection in the direction of one of the covers. Another possibility for the differential analysis in a multiple arrangement of resonators consists in picking up two oppositely directed measurement signals at two different resonators, which additionally has the advantage that interfering accelerations are averaged out during the differentiation of the measurement values.

Figures 2a and 2b show the front and the rear of a sensor element 10 with a resonator 51. The resonator 51 is connected via webs 521 and 522 to a frame 11. In addition, the resonator 51 is printed on both sides with electrodes 551 and 552 which in each case can be connected via feedlines 532 and 571 and connecting pads 543 and 583. In addition, a conductor track 531, which is used for electrodynamically driving the resonator and can be connected via connecting pads 541 and 542, is applied to the front. At the rear, a conductor track 572, at which a voltage can be picked up which is used for controlling the drive and which can also be connected via connecting pads 581 and 582, is applied. The embodiment of the rate-of-rotation sensor according to the invention shown in Figure 2 requires a top and a bottom cover in which in each case counterelectrodes for the electrodes 551 and 552 are applied. In addition, a magnetic field B which is oriented perpendicularly to the surface of the sensor element 10 is required for the electromagnetic drive.

Figure 3a shows a detail of a sensor element which is structured from a ceramic substrate 71 and to which additional masses 731 and 732 are applied to the top and to the underside in the area of the resonator. Electrodes 751 and 752 are printed on both sides onto the additional masses 731 and 732. The webs 761 are only formed in the ceramic substrate 731. For the layered structure of the sensor element, it is necessary to apply compensating layers 741 and 742 corresponding to the additional masses 731 and 732 of the resonator in the area of the frame. The compensating layers 741 and 742 and the additional mass 731 and 732 can be advantageously implemented in the form of ceramic substrates which are structured by laser beam and which are connected to the ceramic substrate 71 by means of thick-film glass. Figure 3b shows a further possibility for implementing a resonator having an increased mass. In this case, the sensor element is built up from three ceramic substrates 71, 741 and 72 which are joined via glass thick films. The ceramic substrate 741 forming the middle layer is structured in such a manner that it is only formed in the area of the frame and of the resonators but is absent in the area of the webs 771 and 772 so that the webs 761 and 762 are exclusively formed by parts of the ceramic substrates 71, 72. The ceramic substrate 741 is used for increasing the mass of the resonator.

In addition to the embodiments shown in Figures 1 to 3, further developments of the rate-of-rotation sensor according to the invention are also possible in which the excitation and/or the signal detection occurs piezoresistively. It is essential to the invention that the sensor structure, that is to say both the mechanical structure and the arrangement of the excitation and signal detection means, is implemented in thick-film technology.

CLAIMS

1. Rate-of-rotation sensor comprising a sensor element which exhibits a fixed frame and at least one resonator which is connected to the fixed frame via one or more webs and is capable of vibrating in two mutually perpendicular directions, with means for exciting the at least one resonator in a first direction of vibration which is located in the plane of the frame, with means for detecting deflections of the at least one resonator in the second direction of vibration as a measurement signal and with at least one cover for the sensor element in the second direction of vibration, characterised in that

- the sensor element (10) has a layered structure, at least one layer being formed by a ceramic substrate,
- in that parts of the frame (11), parts of the at least one resonator (21, 31, 411, 412) and the webs (22, 32, 421, 422) are structured from the ceramic substrate,
- and in that circuit elements for exciting the at least one resonator (21, 31, 411, 412) and for detecting measurement signals are applied to the ceramic substrate in thick-film technology, by means of thick-film pastes applied in a screen printing process and subsequently burnt.

2. Rate-of-rotation sensor according to Claim 1, characterised in that piezoelectric thick-film pastes are applied to the webs and/or the at least one resonator as means for exciting the at least one resonator in the first direction of vibration.

3. Rate-of-rotation sensor according to Claim 1 or 2, characterised in that the ceramic substrate is a piezoelectric ceramic having a polarisation suitable for exciting the at least one resonator in the first direction of vibration.

4. Rate-of-rotation sensor according to Claim 1, characterised in that at least one conductor track (23) is applied to the frame (11), the webs (22) and/or the resonator (21) as means for exciting the at least one resonator (21, 31, 411, 412) in the first direction of vibration, which conductor track can be connected via connecting pads (241, 242) in such a manner that when an excitation voltage is applied, a current (I) flows essentially perpendicularly to the first direction of vibration, and in that means exist for applying a magnetic field (B) in the second direction of vibration.

5. Rate-of-rotation sensor according to Claim 4, characterised in that a further conductor track (33) is applied to the frame (11), the webs (32) and/or the resonator (31), which conductor track is essentially oriented perpendicularly to the first direction of vibration and can be connected via further connecting pads (341, 342) so that a control voltage (U) can be picked up when the resonator (31) moves in the first direction of vibration and when the magnetic field (B) is present, and in that means exist for controlling the current (I) as a function of the control voltage (U).

6. Rate-of-rotation sensor according to one of the preceding claims, characterised in that at the top and at the underside of the at least one resonator (51), means for detecting deflections of the resonator (51) in the second direction of vibration are in each case arranged which in each case supply measurement signals, and in that a deflection of the resonator (51) in the second direction of vibration is detected as difference between the measurement signals.

7. Rate-of-rotation sensor according to one of the preceding claims, characterised in that the sensor element (10) exhibits at least one first resonator (21) having means for excitation in the first direction of vibration and at least one further resonator (31, 411, 412) mechanically coupled to the first resonator (21), in that means for detecting deflections of the resonators (21, 31, 411, 412) in the second direction of vibration

are arranged on at least two different resonators (21, 31, 411, 412), at least two deflections in opposite directions being detected as measurement signals, between which the difference is formed.

8. Rate-of-rotation sensor according to one of the preceding claims, characterised in that the measurement signal is detected by means of thick-film resistors or strain gauges applied to the surfaces of the webs and/or of the at least one resonator in areas of maximum strain.

9. Rate-of-rotation sensor according to one of the preceding claims, characterised in that the ceramic substrate is a piezoelectric ceramic having a polarisation which is suitable for detecting the deflections of the at least one resonator in the second direction of vibration.

10. Rate-of-rotation sensor according to one of Claims 1 to 7, characterised in that at least one electrode (451, 452), which forms the first electrode side of a measuring capacitor, is applied to the surface of the at least one resonator (41) facing the at least one cover (131, 132), and in that at least one further electrode (141, 142), which forms the second electrode side of the measuring capacitor, is applied to the surface of the at least one cover (131, 132) facing the at least one resonator (41).

11. Rate-of-rotation sensor according to one of the preceding claims, characterised in that at least one additional mass (731, 732) is applied, preferably by overglazing, to the ceramic substrate (71, 72) of the at least one resonator.

12. Rate-of-rotation sensor according to one of the preceding claims, characterised in that the sensor element exhibits a first layer which is formed by a first ceramic base (71), in that the sensor element exhibits a second layer which is formed by a second ceramic base (72) and is connected via at least one intermediate layer (741) to the first layer, in that the webs (761, 762) are formed in the two ceramic bases (71, 72), and in that the at least one resonator is formed in the first layer, the

at least one intermediate layer (741) and the second layer.

13. Rate-of-rotation sensor according to Claim 12, characterised in that the at least one intermediate layer is a structured ceramic substrate.

14. Any of the sensors substantially as herein disclosed with reference to the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

9126768.2

Relevant Technical fields

(i) UK Cl (Edition K) G1G (GPGA, GED)

(ii) Int Cl (Edition 5) G01C (19/56), G01P (9/04)

Search Examiner

J M MCCANN

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

24 MARCH 1992

Documents considered relevant following a search in respect of claims ALL

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2186085 A (CHARTER STARK DRAPER) - Figure 1, page 1, lines 47 to 65	1,8,11

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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