Coupling device for coupling vibration systems

The present invention relates to coupling devices for coupling two vibration systems and micro-electro-mechanical components, such as inertial sensors, angular rate sensors and the like, that have two coupled vibration systems.

In micro-electro-mechanical systems (MEMS) such as inertial sensors or gyroscopes, there is often a technical need to have masses vibrate in push-pull mode, for example, to create a force and torque-free system. If both masses are on a line of movement, then spring mechanisms are often used which can impart coupling for synchronized vibration of both masses (common mode) or vibration of both masses in the opposite direction (push-pull mode).

The common mode essentially corresponds to a non-utilization of the spring mechanism. A spring stiffness allocated to the common mode is therefore less than a spring stiffness allocated to the push-pull mode. Based on the relationship for the natural frequency $\omega=\sqrt{k/m}$ (k: spring stiffness, m: mass), it follows that the natural frequency/resonance frequency ω for the common mode is, as a rule, lower than the natural frequency/resonance frequency for the push-pull mode.

Usually, however, push-pull coupling is necessary for the advantageous design of the function of the MEMS. Embodiments of the present invention disclose a coupling device and a micro-electro-mechanical component including the coupling device, for which push-pull coupling is not energetically disadvantaged compared to common-mode coupling.

According to a first aspect of the present invention, there is provided a coupling device for coupling two vibration systems, which are mounted above a substrate such that the vibration systems are linearly arranged along a first direction and can vibrate along the first direction, includes a closed spring structure which can be connected to the vibration systems on outer faces opposite each other along the first direction, and an anchor structure, which is rigidly connected to the substrate and which is arranged within the closed spring structure and is connected to the spring structure on two inner faces opposite each other along a second direction that is orthogonal to the first direction, wherein the coupling device that is connected to the vibration systems

imparts push-pull coupling of the vibration systems as the mode with the lowest frequency, and the anchor structure is configured as a single anchor lying in the center of the spring structure, or the anchor structure includes two anchors which are arranged on the first axis of symmetry.

A closed spring structure, i.e., an essentially linear, deformable structure that has no open ends (and can therefore be topologically deformed into a circle), to which only two vibration systems are connected, performs vibration, in which the two vibration systems are guided in common mode, as the lowest vibration mode, i.e., as the mode with the lowest vibration frequency. This vibration mode is suppressed if the spring structure is connected to the substrate via two points, the connecting line of which is perpendicular to the vibration direction of the vibration systems or the connecting line of which is between the connections of the spring structure to the vibration systems. This connection ensures that at least the same amount of energy must be used for displacement of the two vibration systems in the same direction as for displacement in the opposite direction. By designing the anchor(s) of the spring structure within the spring structure, this can be achieved in a space-saving manner.

The spring structure can be configured symmetrically at least with respect to two axes of symmetry that are perpendicular to each other. The two vibration systems can be connected to the spring structure along the first axis of symmetry, and the two connections of the spring structure to the anchor structure can lie along the second axis of symmetry. The symmetrical design of the spring structure makes it easier to determine possible deflections, i.e., the eigenmodes and their excitation energies. In addition, equal forces on the two vibration systems lead to equal deflections if the spring structure is configured symmetrically.

In so doing, the spring structure can deform in the opposite direction to the same extent along the second axis of symmetry when deformed along the first axis of symmetry. This means that a deflection of the vibration systems by a certain amount leads to a deformation of the spring structure along the first axis of symmetry, which is accompanied by a deformation of the spring structure along the second axis of symmetry, the deflection of which is in relation to the amount of deflection of the vibration systems (e.g., proportional or equal to it). This deformation makes coupling to the push-pull mode "softer" than coupling to the common mode, i.e., the spring

constant that can be allocated to the push-pull mode becomes less than the spring constant that can be allocated to the common mode. As a result, the natural frequency of the push-pull mode becomes less than that of the common mode, whereby the push-pull mode becomes more energetically favorable than the common mode.

Furthermore, the coupling device can have first spring elements that connect the anchor structure to the spring structure. In this case, the first spring elements can essentially only be deflected along the second direction. The connection of the spring structure to the substrate is therefore again provided via bendable or deformable elements, e.g., via a double-folded bending beam spring. This means that the points at which the spring structure is connected to the substrate do not have to be fixed if the spring structure is deformed, but can vibrate along the second direction, i.e., perpendicular to the direction of vibration of the vibration systems. This enables the formation of eigenmodes that impart a push-pull mode of the vibration systems and have a lower natural frequency/are energetically more favorable than modes that lead to a common mode.

Furthermore, the coupling device can have second spring elements via which the vibration systems can be connected to the spring structure. In this case, the second spring elements can essentially only be deflected along the first direction. The second spring elements thus serve to simplify the coupling of the vibration systems to the spring structure. Due to the second spring elements, the vibration behavior of the spring structure can be made even more flexible, since a rigid coupling of the spring structure and vibration systems is omitted, which requires a slavish synchronization of the corresponding parts of the spring structure with the vibration systems.

The anchor structure can be configured as a single anchor lying in the center of the spring structure. This means that there is only one connection point via which the spring structure is connected to the substrate. This can be advantageous from a manufacturing point of view. In addition, a single connection to the substrate allows a larger number of different vibration modes, whereby the coupling device can be used in a variety of applications.

However, the anchor structure can also include two (or more) anchors that are arranged on the first axis of symmetry, i.e., on the direction of vibration of the two vibration systems. Rotational movements of the spring structure, in particular, can thereby be suppressed. However, the plurality of anchors can also be arranged along the second axis of symmetry.

The spring structure can be configured in a circular, rectangular, square, hexagonal, elliptical or diamond-shaped manner. This simplifies the manufacture of the spring structure.

If the spring structure is configured in a rectangular, square or hexagonal manner, the connections to the two vibration systems and to the anchor structure can be designed on the sides of the rectangle, the square or the hexagon, respectively. In case that the spring structure is configured in a square, diamond-shaped or hexagonal manner, the connections to the two vibration systems and to the anchor structure can be configured in the corners of the square, the diamond or the hexagon, respectively. This type of symmetrical coupling improves the vibration behavior of the coupling structure and ensures that the common mode is no longer preferred.

According to a second aspect of the present invention, there is provided a micro-electro-mechanical component that includes the coupling device as described above and the two vibration systems that are connected to the spring structure of the coupling device. In such a micro-electro-mechanical component, the advantages described above can be achieved.

The invention will be described in detail in the following text, with reference to the figures. The description and figures are purely exemplary. The invention is defined solely by the claims.

Fig. 1 shows a schematic diagram of a coupling device;

Fig. 2 shows a schematic diagram of another coupling device;

Fig. 3 shows a schematic diagram of a micro-electro-mechanical component