

COUPLED RESONATOR FOR REGULATING SYSTEM

Field of the invention

The present invention concerns a coupled resonator for a regulating system, i.e. an assembly formed of two resonators, the coupling of which stabilises a frequency and thus makes it more independent of external influences. The invention will be illustrated more specifically by the regulating system of a mechanical timepiece movement for which isochronism is a quality criterion.

Background of the invention

Numerous devices have already been proposed for stabilising the frequency of a sprung balance regulating system. GB Patent No. 1 138 818, published in 1967, discloses a coupling device wherein the vibrations of a first oscillator excite a tuning fork via shocks, i.e. without any direct mechanical link. More recent regulating devices rely essentially on devices associating a mechanical regulator, such as a sprung balance, associated by electromagnetic coupling with an electronic regulator, said coupling being essentially achieved by means of magnets arranged in the arms or in the felloe of the balance. This type of device has been disclosed, for example, in US Patent No. 3 937 001. Numerous improvements have been made to this basic device; essentially concerning the design or arrangement of the magnets, the electronic circuit and the second resonator, and the energy source necessary for powering said electronic circuit. Such improvements are for example disclosed in EP Patent Nos. 0 679 968, 0 732 243, 0 806 710, 0 822 470, 0 848 306, 0 935 177 and 1 521 141.

All of these coupling devices have the drawback of being either unreliable, or requiring the assembly of a large number of components whose peculiar functions have to be adjusted in relation to each other, which eventually contributes to greatly increasing the cost of the final product.

Summary of the invention

It is thus an object of the present invention to overcome the drawbacks of the aforecited prior art by providing a coupled resonator of simpler and more reliable design.

The invention therefore concerns a coupled resonator including a first low frequency resonator, for example of the order of several hertz and a second higher frequency resonator, for example of the order of 100 Hz. The invention is characterized in that the first resonator and the second resonator comprise permanent

mechanical coupling means for stabilising the frequency in the event of external interference, for example in the event of shocks.

The two resonators can be manufactured separately in identical or different materials, then mechanically assembled by any means known to those skilled in the art, such as by bonding, rivets, welding or snap fit.

The two resonators can also be manufactured in a single piece in a single material.

The materials used must have a certain elastic constant and may for example be chosen from among metals or alloys, or amorphous, monocrystalline or polycrystalline materials, such as glass, quartz and silicon or its compounds.

The invention will be more particularly illustrated by a coupled resonator formed by a balance spring and a tuning fork, this type of resonator being able to be incorporated in the regulating system of a timepiece, in particular a wristwatch, likely to undergo shocks.

Brief description of the drawings

Other features and advantages of the present invention will appear in the following description of an example embodiment, concerning the regulating system of a mechanical timepiece movement, given by way of non-limiting illustration, with reference to the annexed drawings, in which:

- Figure 1 shows a first embodiment;
- Figure 2 is a partial diagram of a second embodiment;
- Figure 3 is a partial diagram of a third embodiment;
- Figure 4 is a graph showing the natural frequencies of the coupled system and
- Figure 5 is a graph showing the influence of the coupling on the frequency stability.

Detailed description of the invention

The invention will be more particularly illustrated by the coupled resonator shown in Figure 1 for maintaining the isochronism of a mechanical timepiece movement.

It basically includes a first resonator formed by a balance spring 1 typically having a frequency of the order of several hertz and a second resonator formed by a tuning fork 2, typically having a frequency of the order of hundreds of hertz. The inner terminal curve 3 of balance spring 1 is fixed in a conventional manner to a collet 5 to secure it to a balance staff and tuning fork 2 comprises, also in a known manner, two

arms 4, 6 connected by a foot 8. Foot 8 of tuning fork 2 is secured in a known manner to a fixed part of the timepiece movement, such as the balance cock.

As can be seen, balance spring 1 and tuning fork 2 are permanently mechanically connected, in this embodiment, arm 6 of tuning fork 2 is extended by the outer curve 7 of balance spring 1.

In other words, the two resonators are made in a single piece, by known techniques that depend upon the materials used. These materials are obviously materials having a certain elastic constant "k", such as metals and alloys, or amorphous, monocrystalline or polycrystalline materials, such as glass, quartz, silicon or its compounds.

The techniques for shaping these materials by stamping, LIGA, etching, photolithography, or other techniques are well known to those skilled in the art and will not therefore be described any further.

This basic embodiment will form an example hereinafter showing how this coupling has a favourable effect upon frequency stabilisation.

Figure 2 shows a variant. This variant differs from the preceding embodiment in that the first resonator, namely balance spring 1, and the second resonator, namely tuning fork 2, are initially two independent parts able to be made of different materials. A mechanical connection is created between these two parts. In the example shown, arm 6 of tuning fork 2 comprises a notch 10 in which the end of the outer curve 7 of the balance spring is engaged, the mechanical connection then possibly being completed by bonding. Other modes of mechanical connection, well known to those skilled in the art, are evidently possible. In the embodiment shown, foot 8 of tuning fork 2 further comprises a neck 12 for attachment to a fixed part of the timepiece movement, and able to influence the coupling constant " k_c " between the two resonators.

Figure 3 shows other variants providing great freedom for adjusting coupling constant " k_c " between the first and second resonator and the natural frequency of the second resonator. As can be seen, foot 8 can comprises recesses in the material that will enable the coupling constant " k_c " to be altered. They could also be made on any other part of tuning fork 2, particularly on the free arm 4 to alter the mass "m" thereof and thus the natural frequency of the tuning fork. Conversely, according to an embodiment that is not shown, it could be possible to add mass at any place on the second resonator.

Figure 3 also shows another variant, which may be combined with the preceding variant, to alter the natural frequency of the first resonator. The free arm 4

comprises an inertia block 16, mobile on said arm 4 and able to be immobilised at a determined place, for example by means of a tightening screw 18.

According to another variant that is not shown, when tuning fork 2 is made of quartz along crystallographic axes for obtaining a piezoelectric effect, electrodes can be provided on arms 4, 6 to generate electrical energy. In the case of a wristwatch, this energy could be used, for example, for lighting the dial.

Referring now to Figures 4 and 5, an example corresponding to a coupled resonator according to the embodiment shown in Figure 1 will now be described. The first resonator has an elastic constant $k_1 = 5 \cdot 10^{-6} \text{ N m/rad}$ and an inertia $I_1 = 16 \cdot 10^{-10} \text{ kg} \cdot \text{m}^2$, which corresponds to a natural frequency $f_1 = 9.2 \text{ Hz}$. The second resonator has an elastic constant $k_2 = 1 \cdot 10^{-4} \text{ N m/rad}$ and an inertia of $I_2 = 5 \cdot 10^{-10} \text{ kg} \cdot \text{m}^2$, which corresponds to a natural frequency of $f_2 = 71 \text{ Hz}$. When the two resonators are mechanically coupled, the value of coupling constant " k_c " depends upon the shape of the foot that joins the two resonators. This coupling frequency was made to vary between the values $1 \cdot 10^{-8}$ and $1 \cdot 10^{-4}$ and is shown in Figure 4 with a logarithmic scale of the natural frequencies of the coupled system. as can be seen, frequencies f_1 and f_2 are influenced by the variation in coupling coefficient k_c .

The graph of Figure 5 shows, as a function of a variation in coupling coefficient k_c within the aforementioned limits, a study of interference in the first resonator due for example to a shock, i.e. a comparison of the effect of the interference on the first resonator frequency variation when it is alone and when it is coupled to the second resonator, assumed to be stable.

As can be seen for a coupling coefficient $k_c \leq 1 \cdot 10^{-6}$ a stabilisation of more than 20% is obtained, which shows the interesting aspect of the coupled resonator of the invention for stabilizing the frequency for example that of regulating system for a timepiece, with a simple and inexpensive design.

CLAIMS

1. Coupled resonator including a first low frequency resonator and a second higher frequency resonator, the first resonator and the second resonator including permanent mechanical coupling means characterized in that the first resonator is a balance spring (1) and in that the second resonator is a tuning fork (2) including two
5 arms (4, 6) connected by a foot (8), one of the arms (6) being secured to the outer curve (7) of the balance spring (1) and the other arm (4) being free.
2. Coupled resonator according to claim 1, characterized in that the free arm (4) of the tuning fork (2) further includes an inertia block (16) able to be moved to
10 resonator.
3. Coupled resonator according to claim 1 or 2, characterized in that the free arm (4) of the tuning fork (2) further includes zones (14) that are easy to machine in order to alter the natural frequency of said fork and thus to adjust the frequency of the coupled resonator.
- 15 4. Coupled resonator according to any of the preceding claims, characterized in that the foot (8) comprises recesses (14) in the material that will enable the coupling constant (k_c) to be altered.
5. Coupled resonator according to any of the preceding claims, characterized in that the foot (8) of tuning fork (2) is secured to a fixed part.
- 20 6. Coupled resonator according to claim 5, characterized in that the foot (8) of tuning fork (2) further comprises a neck (12) for attachment to a fixed part of the timepiece movement, and able to influence the coupling constant (k_c) between the two resonators.
7. Coupled resonator according to any of the preceding claims,
25 characterized in that the first resonator has a natural frequency of the order of several hertz and the second resonator has a natural frequency of the order of hundreds of hertz to several hundred hertz.
8. Coupled resonator according to any of the preceding claims, characterized in that the first and the second resonator are made of identical or
30 different materials and are assembled by bonding, rivets, welding, snap fit or other means.
9. Coupled resonator according to any of the claims 1 to 7, characterized in that the first and the second resonator are integral and made of the same material.
10. Coupled resonator according to any of the preceding claims,
35 characterized in that the materials used for the first and second resonators are

selected from among metals or alloys, or amorphous, monocrystalline or polycrystalline materials, such as glass, quartz and silicon or compounds thereof.

11. Coupled resonator according to claim 10, characterized in that, when the material is quartz and when said resonator has been shaped along crystallographic orientations for obtaining a piezoelectric effect, the arms (4, 6) of the tuning fork (2) further comprise electrodes for generating electrical energy.

12. Timepiece with a mechanical movement, characterized in that it includes as a regulating system a coupled resonator according to any of the preceding claims.